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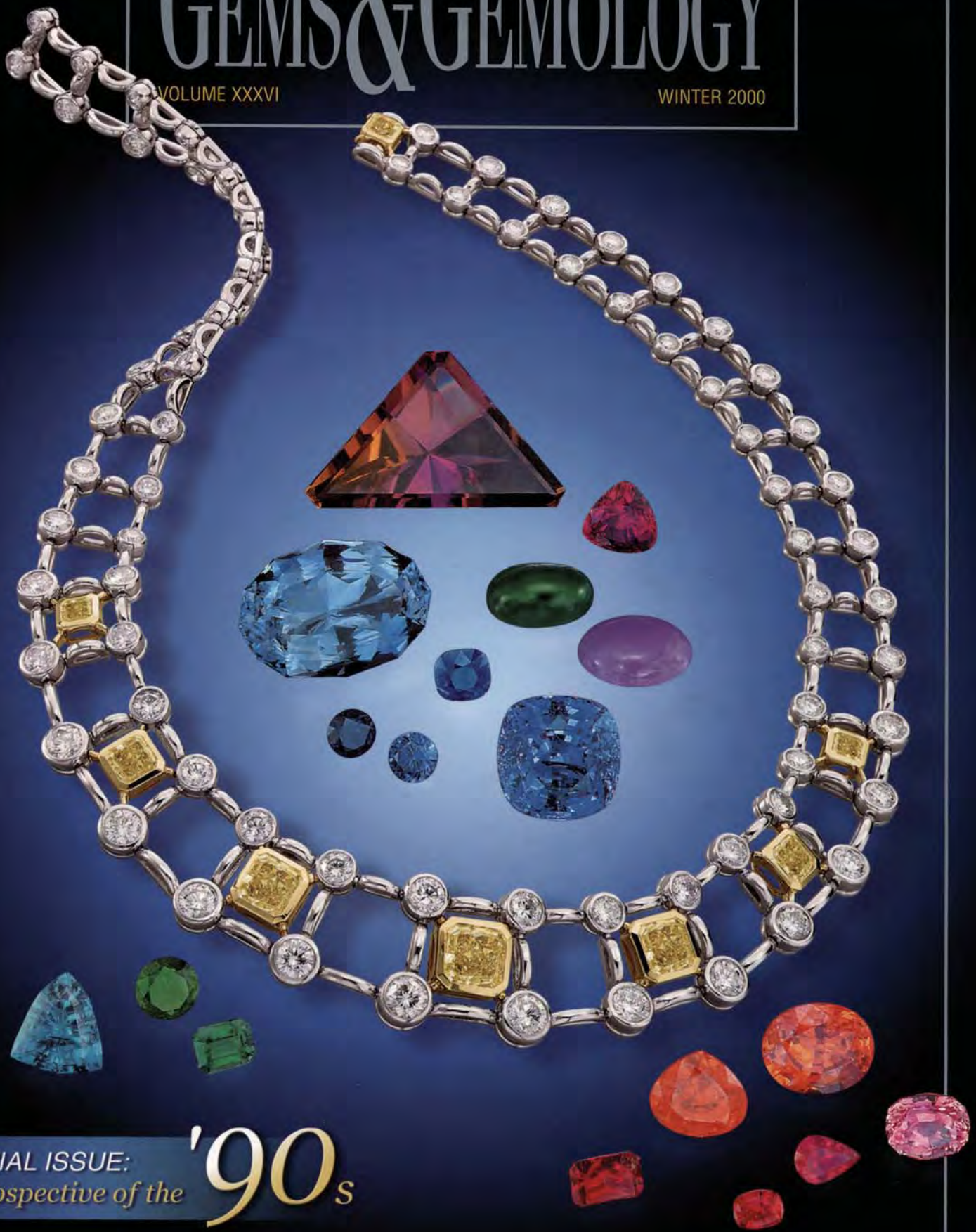

SPECIAL ISSUE: Retrospective of the '90s

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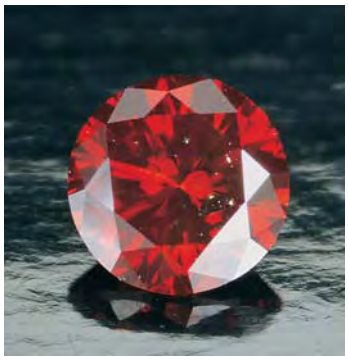
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ABOUT THE COVER

Color was the watchword of the '90s in gems, jewelry, new synthetics, and even treatments (which saw the introduction of *decolorization* in diamonds). This photo includes some of the newest and most popular colored gems of the decade, as well as a contemporary yellow and "white" diamond necklace set in the decade's most prominent jewelry metal, platinum. Shown here, as keyed to the drawing to the right, are: (1) 41.62 ct ametrine, (2) 7.71 ct green jadeite, (3) 7.81 ct violet jadeite, (4) 27.23 ct aquamarine, (5) 1.28 ct blue spinel, (6) 1.17 ct benitoite, (7) 2.14 ct blue sapphire, (8) 23.18 ct blue spinel, (9) 4.82 ct purple sapphire, (10) 5.32 ct Paraíba tourmaline, (11) 2.16 ct demantoid, (12) 1.05 ct emerald, (13) 1.99 ct red beryl, (14) 0.72 ct ruby, (15) 1.15 ct purple-pink sapphire, (16) 5.54 ct spessartine, (17) 8.04 ct orange sapphire, and (18) 3.48 ct pink spinel. The necklace contains 25.85 ct of radiant-cut and round brilliant diamonds. Loose stones from the collection of Michael M. Scott; photo © Harold & Erica Van Pelt—Photographers, Los Angeles. Necklace courtesy of Louis Glick, New York.

A Retrospective of the '90s: The Challenge of Change

The decade of the '90s was one of unparalleled change and the inevitable challenges that result from it. Like other industries, the gem world was buffeted by an unprecedented *pace* of change, led by a veritable revolution in technology. The decade opened with what was perceived to be the very real threat of synthetic gem diamonds in the marketplace. Perhaps not ironically, it closed with another threat to the diamond industry: that of "unidentifiable" high pressure/high temperature annealing in diamonds.

Once again, protecting the integrity of natural, untreated gems dominated the arena of gemological concerns. It is perhaps, then, only fitting that the core objective of GIA and other research laboratories is the ability to differentiate between natural gems and laboratory-grown materials, as well as between natural and treated gems. The essence of gemology lies in our ability to identify these materials and to distinguish any artificially induced change. If rarity ever becomes a meaningless virtue, then the backbone of the trade—the *magic* of the natural gemstone—will be broken.

At the 1991 International Gemological Symposium, I said that the technology of gem identification would need to keep pace with the technology of gem synthesis and treatment. Our predictions about the proliferation of synthetic colored stones have come true, and new identification criteria continue to be developed to address them. Although synthetic diamonds still are not widely available, the decade saw advances in identification techniques and instruments which ensure that these synthetics can be detected when they are brought into a well-equipped gemological laboratory. GIA Chairman Richard T. Liddicoat said years ago that the production of gem-quality synthetic diamonds alone was perhaps the last great gemological barrier to be breached. Yet new barriers continue to be raised. Never has the role of the gemologist been more important.

And never has the challenge of treatments been so real. One only has to recall the fear that gripped the industry when the "filling" of surface-reaching breaks in polished diamonds became available. Or the devastation inflicted on the emerald market when the stability of new and even traditional fillers became questioned. Most recently, the discovery of "glass" fillings in heat-treated rubies has undoubtedly affected demand for these stones. Despite the overall growth of the jewelry market, this has not been an easy decade for gems.

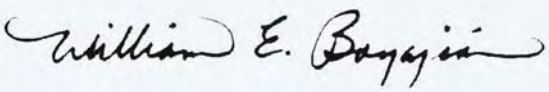
The '90s also saw the rapid development of computerized equipment in cutting factories, in quality analysis, and in advanced identification techniques. With the availability of greater computer power and programming ability, *cut* in diamond became an important focus. Researchers were able to analyze proportions scientifically in ways never before imaginable. Most interesting is how innovations in instrumentation have integrated with innovations in communication. During the '90s, the Internet revolutionized what faxes and other sophisticated telecommunications started in the '80s.

However, in addition to articles on synthetics, treatments, and new technologies, this *Retrospective* issue looks at the two "anchors" of gemology: the localities from which gems emerge, and the jewelry into which they are placed. Gem localities determine what will be available to jeweler and consumer alike, not only in terms of which gem materials, but also in terms of what colors, sizes, and qualities will be seen on the market. With cultured pearls in particular, the decade was highlighted by the influx of major amounts of multicolored goods from French Polynesia, golden and white cultured pearls from the South Seas, and myriad shapes and colors from China. And where would we be without the process of incorporating beautiful cut and polished gemstones into fine rings, necklaces, bracelets, and the like? How can we truly understand the priorities of our gemological agenda without knowing the end product: cherished jewels?

Let us not forget, too, the economic context in which all of these developments took place. The '90s began with a recession and were plagued by the Asian downturn later in the decade. Japan struggled through most of this period, while the United States enjoyed sustained economic growth.

The industry itself was affected by the way gems are mined, marketed, and merchandized. In diamonds especially, the mine-to-market process has been severely tested. Vertical integration and strategic alliances have placed pressure on sources, manufacturers, and dealers alike. In light of De Beers's recently stated shift from controlling diamond supply to driving diamond demand, alternative channels will undoubtedly emerge. Another nascent factor is the so-called conflict diamonds issue, the desire to exclude from the marketplace diamonds that are sold to purchase weapons used to fuel civil conflict. It is surely difficult to know the future of this situation, despite the industry's dedication to eradicating the problem.

In a sense, what we have provided in this *Retrospective of the '90s* issue is a snapshot of a decade—and a profound one at that—from mining and localities to treatments and synthetics to finished gemstones and jewelry. Our goal was to produce a valuable, thoroughly readable contribution to your gemological library: a decade of gemological knowledge brought together in a single journal. I hope you enjoy and benefit from this important issue.



William E. Boyajian, President
Gemological Institute of America

Top: GE POL diamond / Bottom: Synthetic diamonds

GEM LOCALITIES OF THE 1990S

By James E. Shigley, Dona M. Dirlam, Brendan M. Laurs, Edward W. Boehm, George Bosshart, and William F. Larson

The past decade saw growth in gem exploration, production, and marketing worldwide. Important colored stone–producing regions included: Southeast Asia (Myanmar, Thailand, and Vietnam), Africa (Tanzania, Kenya, Zimbabwe, Nigeria, and Namibia, as well as Madagascar), South America (Brazil and Colombia), central and southern Asia (Sri Lanka, India, Afghanistan, Pakistan, Russia, and China), and Australia. The major sources for diamonds were Australia, central and southern Africa (Botswana, South Africa, Namibia, Angola, and Zaire), and Russia (mainly in the Republic of Sakha), with exciting discoveries in northern Canada. Cultured pearls from French Polynesia, Australia, and China became increasingly important, as production from Japan declined. This article provides a comprehensive overview of those gem deposits that were either new or remained commercially significant in the last decade of the 20th century.

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Please see acknowledgments at the end of the article.

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During the 1990s, new finds of gems created interest and excitement among both jewelers and consumers. These included ruby from Mong Hsu, Myanmar (Burma); blue and pink sapphires from Madagascar; a wide variety of colored stones from southern Tanzania; spessartine garnet from Nigeria and Namibia; exceptional peridot from Pakistan; and pink to red tourmalines from Nigeria and Brazil. Diamond was mined in northern Canada for the first time. Names such as *Tunduru*, *Ilakaka*, and *Ekati* were unknown to the gem trade in the 1980s, and yet they are now commonplace when we speak of important gem localities at the dawn of the 21st century. Through the efforts of independent prospectors and small groups of miners, as well as multinational exploration companies—stimulated by strong consumer demand—the 1990s witnessed a proliferation of gem sources. Gem localities continue to intrigue consumers because they create an integral part of the romance and lore that are associated with gemstones, an opportunity to purchase a symbol of beauty and rarity from a remote land (figure 1).

This article updates the 1980s survey published by Shigley et al. in the Spring 1990 Retrospective issue of *Gems & Gemology* by identifying key localities discovered during the past decade, and highlighting deposits that either attained or continued at commercial levels of production during this period. We have also included newer or less-explored localities that may have potential in the future. Most of our coverage is limited to the more commercially important gem materials (i.e., emerald and other beryls, alexandrite and other chrysoberyls, ruby and sapphire, diamond, garnet, jade [both jadeite and nephrite], opal, peridot, quartz, spinel, tanzanite, topaz, and tourmaline). Locality information is both summarized in the text and listed in greater detail in table 1 at the end of the article. In table 1, the more commercially significant localities (according to our best understanding) are designated in bold type; citations are to the most relevant articles

Figure 1. Several new gem sources joined traditional localities as important producers in the 1990s. The sapphires and rubies in this necklace come from a number of sources, but predominantly Sri Lanka. Accented with smaller diamonds, the 129 gem corundums have a total weight of 280.45 ct. Jewelry manufactured by Wilson Benito; courtesy of Richard Stoich and Quyen Cao. Photo © Harold & Erica Van Pelt.

on each locality for convenient reference (personal communications are used where published information is not available). In addition, selected localities are plotted on five maps (see enclosed chart) that show several major gem-producing regions (southern Africa, South Asia, Southeast Asia, Australia, South America). Although there has been some notable production in the areas omitted (e.g., Russia, North America, western Africa, and China), they were less significant—in terms of the variety of gems produced—during this decade than localities in the five regions mentioned. Separate lists are provided for localities producing less-prominent gems (i.e., apatite, benitoite, charoite, chrome diopside, feldspar, iolite, lapis lazuli, maw sit sit, red beryl, rhodochrosite, rhodonite, scapolite, sphene, spodumene, sugilite, turquoise, and zircon), as well as for regions important for cultured pearls; see tables 2 and 3, respectively, also at the end of the article.

SOURCES AND PRESENTATION OF INFORMATION

The gem locality information in this article comes from four main sources:

1. Published articles in the scientific and trade literature
2. Personal communications with individuals who are directly involved with gem mining or who purchase gem rough at mining sites
3. The authors' knowledge about the sources of commercially significant gem materials encountered in the trade during the past decade, including information on the kinds of gems that were submitted to the GIA Gem Trade Laboratory and the Gübelin Gem Lab
4. Visits by the authors to some gem-mining locations

Information for each locality is referenced according to what we deemed to be the best and most recent publications. However, the commercial significance of a gem locality is not always matched by the quantity or quality of relevant published information. Thus, over the past decade, published articles are lacking for some major gem deposits (especially those that have been mined for a considerable period). In such cases, earlier literature references are cited in the tables, or the listing of the locality is based on knowledge of the authors or respected colleagues. For gem localities of the 1980s where significant mining has continued, the literature citations in Shigley et al. (1990) are still valid (but are not given again here for brevity). Rather than cluttering the text with references, we decided to give most of the published citations primarily in the three tables. Again for the purpose of brevity, in the text we discuss most of the locality information with a general reference to the country rather than to the specific mine or region. For more on the specific localities, consult tables 1, 2, and 3.

There may be inconsistencies in spellings and diacritical marks (e.g., accents, umlauts, etc.) when some locality names are translated into English. We used the *Microsoft Encarta 99 Virtual Globe* software program, which is an electronic atlas, as a guide to both geographic information and locality name spellings.

In the text below, the gem materials are presented alphabetically, but within each category, the most important subgroup is mentioned first.

A separate box A is included to give the reader an

Figure 2. Colombia has remained the world's most important source of fine emeralds. The Colombian emerald in this pendant weighs 8.40 ct. Courtesy of H. Stern; photo © Harold & Erica Van Pelt.

idea of prices for some key gem materials during the '90s. This box was prepared by Richard Drucker, publisher of *The Guide*, which provides diamond (bimonthly) and colored stone (biannually) wholesale pricing information based on market activity. While *Gems & Gemology* does not typically report gemstone prices, those authors who are involved in the trade (EWB and WFL) believe that the figures given in box A are a good general representation of average prices during the past decade for the gems described.

Figure 3. Saturated-color aquamarine comes from relatively few deposits, and Africa was the most important source of this material during the 1990s. These aquamarines (9.05 and 4.90 ct) are from Mozambique. Courtesy of Steve Avery; photo by Robert Weldon.

BERYL

Emerald. Colombia still reigned throughout the 1990s as the principal source of fine-quality emeralds (figure 2), with the mining districts at Muzo and Coscuez, and to a lesser extent at Chivor, accounting for most production. In each of these districts, there are ongoing efforts to modernize mining operations to increase yield. Geologic studies of the Colombian emerald deposits have led to new insights into conditions of emerald formation by crystallization from hydrothermal solutions (see, e.g., Ottaway et al., 1994; Giuliani et al., 1995, 2000). Decreasing reserves at the historic mines have prompted active exploration in this region (Schwarz, 1999).

Emerald mining also continued at traditional sources in Brazil and Africa. Large quantities of Brazilian emeralds entered the market in the early '90s, particularly from Goiás and Minas Gerais (primarily the Nova Era area). By the middle of the decade, however, there was an abrupt decline from Minas Gerais due to decreased reserves and reduced demand. Emerald production in Brazil has since continued to decline.

Several sources in Africa produce attractive emeralds. Zimbabwe's Sandawana mine is noted for small stones (0.05 to 1 ct) of high quality. Madagascar and Zambia tend to produce cleaner but slightly darker emeralds than the deposits in Colombia; however, cut stones over 5 ct are quite rare.

Considerable excitement was generated in the early 1990s by renewed activity at the historic emerald mines in Russia's Ural Mountains (e.g., Schmetzer et al., 1991), but these mines never redeveloped into the important commercial sources that they once were.

Deposits in Afghanistan (Panjshir Valley) and Pakistan (Swat Valley) produced fine-quality emeralds of small average size, but mining activities were limited by economic (i.e., lack of profitability) and sociopolitical factors in both countries.

During the past decade, surface-reaching fractures in many emeralds were filled with a wider variety of oils (including cedarwood oil) and resins (such as Opticon and "Palma"), and the infilling process became a major topic of discussion in the trade. Due to concerns over the disclosure of this treatment and the durability of the substances used,

there was a decline in the overall demand for emeralds and in their prices during the latter half of the decade (Weldon, 1997; see also box A). This was especially a problem for emeralds from Colombia and Brazil, which led to greater market demand for African emeralds. The latter generally have fewer fissures, and thus they are less likely to have been treated. By the end of the decade, however, dealers reported that the market for Colombian emeralds had begun to improve.

Aquamarine and Other Beryls. The major sources of gem aquamarine continued to be the same as those of the previous decade, with numerous deposits in Brazil providing much of the supply (although material of African origin was also being imported into Brazil for cutting and reexport). The African sources were Nigeria, Mozambique (figure 3), Zambia, and Madagascar. In particular, the availability from Zambia and Mozambique of fine, saturated-color aquamarine that required no heat treatment helped revitalize the market for this material, which had suffered from declining demand when large quantities of irradiated blue topaz created an inexpensive alternative during the 1980s. Pegmatite miners working in the Lukusuzi game park area in Zambia (bordering Malawi and Mozambique) used creative methods to obtain aquamarine without explosives: They built fires under massive aquamarine-bearing quartz bodies, and then threw water onto the heated rock to fracture it, thereby facilitating the removal of the aquamarine (M. Sarosi, pers. comm., 1999). In general, most aquamarine is heat treated to improve its color.

Production of other beryl varieties (morganite and heliodor) also continued at previously known deposits. Large greenish yellow heliodor crystals from the Ukraine were heat treated to produce aquamarine. Although initially available in large quantities, the stockpile of these crystals was exhausted by the mid-1990s. The interest shown, and investments made, by major mining companies led to increased production of red beryl (figure 4) from the Wah Wah Mountains in southern Utah. Due to its dramatic red color, there was significant demand for this material in Japan. Marketing of red beryl under the trade name "Red Emerald" created controversy toward the end of the decade (Weldon, 1999).

CHRYSOBERYL

The major sources of chrysoberyl (including both cat's-eye [figure 5] and alexandrite) continued to be

Figure 4. Gem-quality red beryl continues to be mined from just one deposit in the Wah Wah Mountains of southern Utah. During the '90s, several mining companies leased the deposit for exploration, evaluation, and production. The bracelet shown here was designed and manufactured by Ray Zajicek/Equatorian Imports, and features 21 red beryls (0.3–0.8 ct each). The ring, designed by Paula Crevoshay, features a 1.66 ct red beryl accented with diamonds. Bracelet courtesy of the Harris family, and ring courtesy of Red Emerald Ltd.; photo by Maha Tannous.

Figure 5. Cat's-eye chrysoberyl is among the most prized of phenomenal stones; the cabochon in the ring on the bottom left weighs 5.95 ct. The other three rings are set with star rubies from Myanmar (7.90, 6.02, and about 15 ct, from bottom right to top left). Photo © Tino Hammid and Christie's Hong Kong.

Figure 6. In Myanmar, rubies are mined from both primary and secondary (alluvial) deposits. At these alluvial workings near Mogok, a series of claims are explored by small groups of independent miners. Photo by Edward Boehm, March 1993.

the alluvial gem fields of Sri Lanka and the pegmatite districts of Brazil. Efforts were underway to reopen some of the classic occurrences of alexandrite in Russia's Ural Mountains, but so far there has been only limited production from mine dumps (N. Kuznetsov, pers. comm., 2000). The most exciting new source of chrysoberyl—including a vanadium-colored green variety as well as alexandrite—has been the Tunduru region of southern Tanzania, which has produced an amazing variety of colored stones. Since late 1998, significant amounts of chrysoberyl (including cat's-eye material and alexandrite) have also been recovered from the Ilakaka alluvial deposit in southern Madagascar. Toward the end of the decade, sources in India (both in Orissa and Andhra Pradesh) provided new discoveries of green cat's-eye chrysoberyl as well as alexandrite.

CORUNDUM

Ruby. The 1990s witnessed continued supplies of ruby from the Southeast Asian countries that historically have been important sources (i.e., Myanmar [figures 5 and 6], Cambodia, and Thailand, with significant decrease in the last; Kane, 1999). In addition to new mines in the traditional Mogok region (Kane and Kammerling, 1992), a major new locality was discovered in Myanmar's Mong Hsu area (Peretti et al., 1995), with millions of dollars worth of ruby from this area entering the market in the past eight years. These rubies typically require heat treatment to remove their distinct blue core. The authors have seen large quantities of fine-color faceted Mong Hsu rubies, usually from 0.5 to 3 ct (see, e.g., figure 7). However, one of us (GB) knows of a substantial number of gem-quality Mong Hsu crystals that weighed well over 100 carats and yielded faceted rubies from 10 to 30 ct.

Figure 7. The most important ruby discovery of the 1990s was in the Mong Hsu region of Myanmar, where enormous quantities have been mined. The crystal shown here is 1.3 cm tall, and the faceted stone weighs 1.16 ct. Courtesy of Pala International; photo © Jeff Scovil.

India and Africa continue to produce primarily cabochon-quality material. African sources include several localities in Kenya, Tanzania, and Madagascar. In particular, the John Saul mine in

Kenya began producing large quantities of (mostly cabochon-grade) ruby after it was reactivated in the mid-1990s (Emmett, 1999b). The ruby occurrences in Malawi, Russia, Nepal, Afghanistan, Pakistan, and China have had little commercial impact to date, but they may prove significant in the future.

The enormous quantity of heat-treated ruby from Mong Hsu that flooded the market in the mid-1990s—as well as the introduction of smaller amounts of Vietnamese material beginning early in the decade—resulted in distinctly lower prices (Federman, 1998; see also box A). Although this decline in price created renewed demand for commercial-quality ruby, the growing prevalence of heat-treated ruby that contained residues of flux materials in healed fractures (see, e.g., Emmett, 1999a) also raised concerns about correct identification and disclosure for gem dealers and consumers alike. During this period, a significant price disparity developed between untreated and treated rubies (Federman, 1998).

Figure 8. A wide variety of colored stones were mined from large alluvial deposits in the Tunduru area of Tanzania, which were discovered in the mid-1990s. These pink and orange sapphires from Tunduru range from 2.78 to 8.33 ct. Courtesy of James Alger Co.; photo by Robert Weldon.

Sapphire. As with ruby, much of the sapphire on the market originated from Southeast and southern Asia (Thailand, Cambodia, Myanmar, Vietnam, and Sri Lanka; again, see figure 1). Although mining continued in Australia, a major producer in the 1980s, production was down significantly by the end of the decade (Aboosally, 1998).

East Africa, particularly the Tunduru region (figure 8), and several areas in Madagascar (figure 9) emerged as the most important commercial sources of blue and pink sapphire. Deposits near Ban Huai Sai in Laos produced primarily smaller, medium to dark blue sapphires that satisfied some of the demand for commercial-grade melee. The output of blue and fancy-color sapphires from Montana in the U.S. fluctuated greatly, with significant quantities produced during the middle of the decade. The gems occurred in a wide variety of colors, in sizes typically

Figure 9. One of the most important gem discoveries of the decade occurred in south-central Madagascar at Ilakaka. Like Tunduru, these extensive alluvial deposits yielded several varieties of colored gems. Here, miners wet-sieve sediments in the Ilakaka River before removing gem minerals by hand; photo by Brendan M. Laurs, December 1999. Fine sapphires, such as the one that produced the 7.32 ct untreated Malagasy stone shown in the inset, are sometimes recovered. Sapphire courtesy of JOEB Enterprises and Pala International; photo © Harold & Erica Van Pelt.

BOX A: GEM PRICES IN THE 1990S

Compiled by Richard Drucker, Publisher, *The Guide*

Since there is not a universally accepted grading scale for colored stones as there is for diamonds, grading and pricing for these gems is more subjective. *The Guide*, an internationally recognized gemstone pricing publication, conducts research with a qualified staff of advisors and research assistants who monitor trade shows, business transactions, and trading networks. For consistency in pricing, *The Guide* has used a comprehensive four-tiered grading scale for nearly 20 years: *Commercial* at the low end, *Good* and *Fine* in the middle, and *Extra Fine* at the high end. For the present analysis, the two middle categories (*Good* and *Fine*) are reported, as they are likely candidates for "jewelry quality." Prices can be considerably higher or lower for the other two categories.

The prices reported here are average wholesale, per the weight unit indicated (all January months for the years 1990–1999). Trends for specific gem varieties are described below, with the prices of major gems graphed in the accompanying charts (figure A-1). Although a gem's locality can play a role in pricing (such as a Burmese ruby or Kashmir sapphire), the information in this box is based on quality only. A Burmese ruby is priced separately in *The Guide*, and is not considered in the charts presented here. Likewise, the sapphire prices summarized in this box are for material from any locality except Myanmar (Burma) and Kashmir. Emerald prices are also generalized, recognizing that some top-quality Colombian emeralds may be priced higher.

Treatment is an important issue in pricing today. Normal (i.e., "traditional") treatments are assumed in pricing, since most gems on the market have undergone some treatment process (for example, the blue color in most aquamarine is produced by heat treatment, as is the blue in most tanzanite). Both ruby and sapphire are assumed to have been heat treated. Excess "glass" residue in the fissures and fractures of a ruby—which results from the use of a flux or other "firecoat" during heat treatment—can lower the value. Fissures in emeralds are typically filled with oil or resin, and the prices here assume a moderate level (i.e., extent) of treatment.

Following is a summary of the data for key gem materials in the 1990s.

Beryl—Emerald. Due to widespread concern over treatments, emeralds lost about half of their value (on average) over the decade (figure A-1, bottom). In recent years, a better understanding of treatments, as well as more comprehensive and descriptive reports of treated emeralds from gem-testing laboratories, appear to have halted the steady decline in prices.

Beryl—Aquamarine. Prices for aquamarine were fairly stable in the 1990s (e.g., at $100–$125/ct for "good" 3 ct stones). Increases in supply and new sources occasionally brought some prices down.

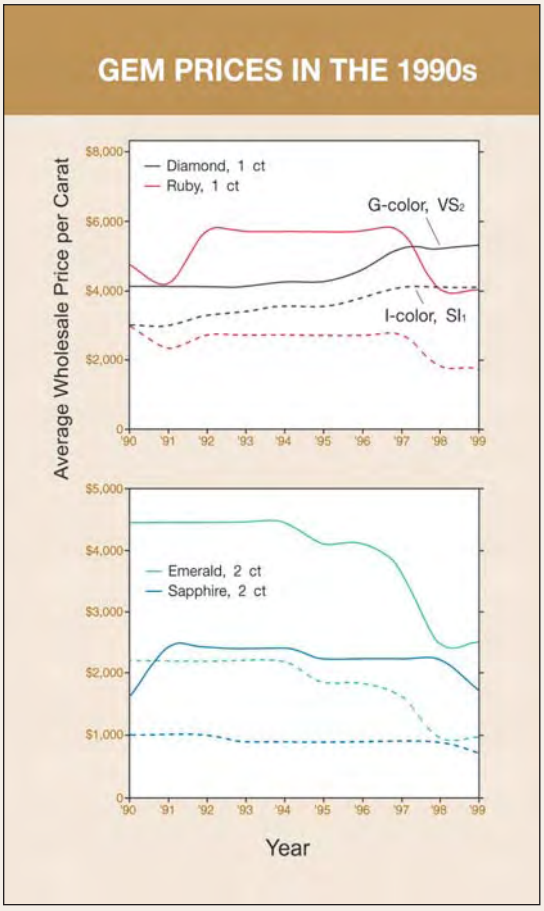

Figure A-1. Average wholesale per-carat prices in the 1990s (for the month of January) are shown for diamond and ruby (top), and sapphire and emerald (bottom). The Guide *categories* Good *(dashed lines) and* Fine *(solid lines) were selected as an index to "jewelry-quality" material. Prices may be considerably higher or lower for other quality grades.*

Corundum—Ruby. As was the case with emeralds, ruby prices were also hurt by controversy over treatments. Not only did the vast deposits discovered at Mong Hsu lead to the greater availability of fine material, but the presence of "glass" residue from the heat treatment of these stones in particular has caused ruby prices to decline over the past three to four years (figure A-1, top).

Corundum—Sapphire. Although sapphire largely escaped the treatment controversy, prices declined recently (figure A-1, bottom) due to the tremendous quantity of stones from Madagascar that have entered the marketplace.

Chrysoberyl—Alexandrite. Long a collector's stone, alexandrite has never been in plentiful supply. When Brazilian miners hit a pocket of alexandrite in 1991, supply increased and, contrary to what was expected, prices went up. Since then, the prices of lower-to-middle grades have remained fairly constant (at about $4,500/ct for 2 ct "good" stones), whereas finer-quality gemstones strengthened in price (from an average low of $5,750/ct in 1990 to $8,000/ct in 1999 for 2 ct "fine" stones).

Diamond (1 ct; G-color VS_2 and I-color SI_1). After an early 1990 price hike by De Beers—which was only partially reflected in diamond prices due to price resistance and absorption by suppliers—prices remained stable, with no official increases until a small one was implemented in early 1993. The period 1995–1997, however, saw larger and more frequent price increases (figure A-1, top). The end result was diamond prices about 30% higher at the end of the decade, especially in the more popular jewelry grades (e.g., $5,300 for 1 ct G-color VS_2 stones in 1999, as compared to $4,100 in 1990).

Garnet—Rhodolite. Rhodolite experienced fluctuating popularity, but its supply was steady and so were its prices (i.e., an average of $25 to $45/ct for "good" and "fine" 3 ct stones).

Quartz—Amethyst. Synthetic amethyst plagued the industry prior to 1990. Today, the problem still exists, but is mostly ignored at the retail level. Nevertheless, wholesale prices of natural amethyst slowly declined over most of the '90s (e.g., from an average of $20/ct down to $12/ct for "fine" 3 ct stones). This was perhaps due to the lack of widespread testing of amethyst and thus the salting of "natural" parcels with synthetic stones.

Spinel—Blue. Prices rose dramatically during the 1990s (e.g., from $125/ct to $350/ct for "fine" 3 ct stones), due to the increased popularity of blue spinel as a nonenhanced alternative to sapphire.

Spinel—Red. Considered by dealers to be an undervalued alternative red gemstone, prices remained stable (e.g., at an average of $200–$250/ct for "good" 2 ct stones), primarily due to a general lack of notoriety. In the mid-1990s, small price increases appeared for finer-quality red spinels, but price resistance eventually negated such gains.

Topaz—Imperial. This variety of topaz was a definite attraction in the tourist markets of the Caribbean, but not a great seller in the U.S. Overall, miners and jewelry stores were successful in raising the popularity and the price of Imperial topaz—by the end of the decade, up to $400/ct for "fine" 3 ct stones in yellow with reddish overtones, for example.

Tourmaline—Pink. For a period, pink was popular. In the early 1990s, prices of pink tourmaline rose in response (e.g., from approximately $85/ct to $100/ct for "fine" 3 ct stones). Subsequently, the prices showed little change.

Zoisite—Tanzanite. The roller coaster of tanzanite pricing resulted from many factors, including supply changes as mines closed and reopened, mining disasters, swings in consumer demand, and governmental controls. With all the fluctuations, however, prices in 1999 were only slightly less than they were at the beginning of the decade (e.g., $325/ct versus $360/ct for "fine" 3 ct stones).

Cultured Pearls—Strands. While prices increased during the first half of the decade, they leveled off quickly as the freshwater Chinese product started to appear. From 1995 to 1999, for example, the price of an 18-inch strand of white, $6^{1}\!/\!_{4}{}^{2}$–7 mm diameter, bead-nucleated cultured pearls averaged $500 for "good" quality, and $875 for "fine."

Cultured Pearls—South Sea and Tahitian. The following discussion is generalized for single, bead-nucleated, round to semi-round, 10–11 mm diameter cultured pearls with thick nacre, medium to high luster, and light blemishes. White South Sea cultured pearls held their value for most of the decade ($1,450 each for "fine" material from 1995 through 1999), although the January 2000 price was just over half that ($775). The prices for black Tahitian cultured pearls started to decline in 1998 (e.g., from $862 each for a "fine" 10–11 mm sample in 1997 to $475 each in the following year). Today, production is much greater and more sources are providing these large pearls, so prices are coming down.

Figure 10. This aerial view of the Argyle diamond mine in northern Australia, taken in February 2000, shows the enormous open pit and tailings piles. During the past decade, this mine has been the world's largest producer of diamonds by volume. Courtesy of Argyle Diamonds.

from 0.2 ct to over 1 ct (R. Kane, pers. comm., 2000).

The heat treatment of sapphires to improve their color and/or clarity remained a major industry in the 1990s. As noted above for rubies, premium prices for untreated blue sapphires are the norm (Federman, 1998). Most heat-treated high-quality blue and pink sapphire came from Sri Lanka and, more recently, Madagascar (Suwa, 1999). In particular, for the last couple of years the Ilakaka deposits have supplied enormous quantities of violet to purple sapphires that can be heat treated to produce pink material (Johnson et al., 1999b).

DIAMOND

All of the traditional diamond sources remained productive, led by the operations in southern and central Africa. The recovery of typically higher-quality diamonds from the seafloor off the coasts of Namibia and South Africa expanded greatly (Rombouts, 2000). In the northeastern part of South Africa, De Beers initiated modernized operations at their new Venetia mine in 1992. In addition, heightened diamond exploration activities during the '90s resulted in several new mining operations and prospects.

After the breakup of the former Soviet Union, a period of uncertainty began in the early 1990s with regard to the continued production of diamonds in Yakutia (now the Sakha Republic in the Russian Federation). Diminished financial resources hindered further development of the major mines in this remote region, especially given the potential need to transform open-pit operations to underground mining. However, progress was made in evaluating a new diamond field in the Arkhangelsk region northeast of St. Petersburg (Sobolev, 1999), although this area has not yet gone into production.

Very large quantities of mainly small brownish to yellow or near-colorless diamonds continued to be recovered from the Argyle mine in northern Australia (figure 10). This mine also produces rare pink-to-red diamonds, which have brought per-carat prices of US$100,000 or more at annual auctions ("Argyle Diamonds...," 1997). Toward the end of the decade, a decision was made to expand the area of the open pit over a two-year period to allow future access to additional ore reserves. However, concern about the number of diamonds that eventually can be recovered economically by open-pit mining has forced additional exploration in the mine area, as well as deliberations over the feasibility of developing underground operations.

One of the more exciting developments in recent years was the discovery of gem-quality diamonds in northern Canada and the subsequent identification of several potentially significant deposits over a wide area. Toward the end of the decade, diamond production began at the Ekati mine in the Northwest Territories (figure 11), with the probability that Canadian diamonds could supply more than 10% of world production by value early in the 21st century (Paget, 1999). Discovery of new diamond deposits has been aided by the use of high-technology exploration methods (thus far, similar methods have not achieved comparable success in locating new colored stone deposits; see Cook, 1997).

Distribution Changes and Branding. As the decade came to an end, the possibility of a "multi-channel" distribution system, with diamonds flowing from the mine to the consumer along several different routes that are not all controlled by De Beers, became a frequent topic of discussion (see, e.g., Sevdermish et al., 1998). The shift toward diamond branding at the end of the 1990s (e.g., efforts to "brand" the origin of diamonds from new deposits in Canada) is likely to increase consumer awareness of their geographic origin. Recently, De Beers acknowledged the reality of the multi-channel distribution system by announcing that rather than attempt to control world diamond supply, they would strive to be the supplier of choice for the industry (see, e.g., Behrmann and Block, 2000).

Country of Origin. For years, "country of origin" has played an important and sometimes controversial role in the marketing of some colored stones. At the end of the '90s, this phrase assumed new importance in the diamond industry, as some organizations and governments became concerned that profits from the sale of diamonds were being used to fund domestic conflicts in certain African countries. Angola, Sierra Leone, and the Democratic Republic of the Congo were singled out as areas of concern. This sparked a demand for documenting the source of such "conflict" diamonds to prevent them from entering the legitimate market. However, determining the geographic origin of diamonds is technically not feasible (Janse, 2000). More and more, efforts by producers and dealers alike are focused on preventing the purchase of diamonds from these areas, and providing documentation with each diamond that verifies its origin from a "nonconflict" source (see, e.g., http://www.gemprint.com; Heeger, 2000).

Figure 11. Canada became a new diamond source in the 1990s, with the opening of the Ekati mine in the Northwest Territories. All of these diamonds were faceted from Ekati mine rough; the marquise weighs 1.75 ct. Courtesy of Barker & Co.; photo © Jeff Scovil.

GARNET

Known sources of garnet—including localities in East Africa, India, and Sri Lanka—remained important. In the Ekaterinburg area of Russia, both the original locality (in the Babrovka River valley) and new deposits (at Karkodino) produced some fine-quality demantoid (figure 12). The first significant demantoid locality outside of Russia was discovered in Namibia in the mid-1990s, although the color of this new material is not as intense, and the stones lack the distinctive "horse-tail" inclusions that are characteristic of Russian demantoid.

Rhodolite and other garnets came from East Africa, while a new deposit of gem-quality grossularandradite was discovered in Mali at Diakon. New sources in Madagascar produced pyrope-spessartine (including color-change material) and tsavorite. Orange spessartine garnets continued to come from Namibia, Madagascar, and Zambia. Just as production from Namibia declined at the end of the 1990s, Nigeria provided larger and cleaner spessartines to

Figure 12. Fine demantoid garnet, such as the 4.49 ct stone shown here, was mined at both old and new localities in the Ural Mountains of Russia. The presence of "horsetail" inclusions (see inset; 1.46 ct) provides confirmation of Russian origin. Courtesy of Pala International; photos by Robert Weldon.

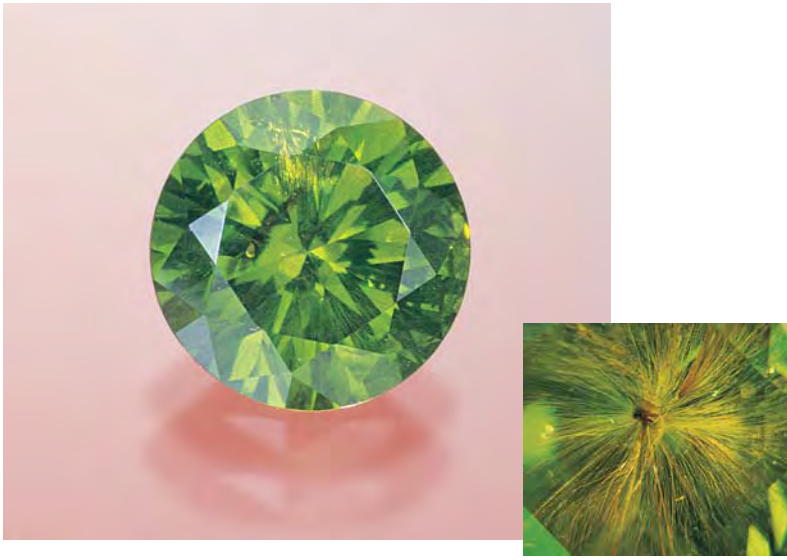

Figure 13. At the end of the decade, relatively large, clean spessartine garnets (such as the 12.97 ct stone shown here) came from a new deposit in southwestern Nigeria. Courtesy of Mayer & Watt; photo © Tino Hammid.

Figure 14. Large quantities of garnets—in several varieties—were recovered from the Tunduru area of Tanzania. The mines are worked by simple methods, as shown by this pit at Libafu. A portable wet-sieving machine is being used to concentrate the gem rough. Photo by Horst Krupp.

meet the market demand created by the Namibian material (see, e.g., Zang et al., 1999; figure 13). The Tunduru region of southern Tanzania has yielded large quantities of several different types of garnet (Henn and Milisenda, 1997; figure 14). A large new deposit in Lindi Province was the source of attractive tsavorite, which has helped replenish the diminishing production from traditional tsavorite localities in Kenya and northern Tanzania (H. Krupp, pers. comm., 1999).

JADE

Northern Myanmar continued to be the sole commercial source of high-quality green, lavender, and white jadeite, as well as other colors, with no shortage of supply in sight (Hughes et al., 2000; figure 15). New jadeite deposits are being exploited in Japan (Chihara, 1999), as well as in both Russia (the Polar Urals and in central Siberia) and southern Kazakhstan (N. Kuznetsov, pers. comm., 2000).

Nephrite deposits are located in the western portions of North America (especially British Columbia in Canada, as well as Alaska). Other deposits occur in Xiu Lan County, Liaoning Province, and other regions of China. As China continues its rapid economic development, it is likely that demand for both nephrite and jadeite jade will also increase in that marketplace.

OPAL

Australian localities in New South Wales, Queensland, and South Australia continued to be the major sources of most gem opal (figure 16). However, Mexico and Brazil were important producers of "fire" opal and white opal. Mexican fire opal experienced strong—but brief—popularity through marketing on television shopping networks. Subsequent problems with supply of this material, and its tendency for crazing, brought its popularity to an abrupt halt (P. and B. Flusser, pers. comm., 2000). Prices for black opal from Lightning Ridge, Australia, declined briefly due to the collapse of the Asian market (especially Japan), but subsequent demand from the strong U.S. market brought prices close to those in the early 1990s.

PERIDOT

The past decade witnessed the continued production of gem-quality olivine from the United States (Arizona), Myanmar, and China. However, the discovery of significant quantities of rich green peridot from Pakistan (figure 17), with exceptional clarity

and in large sizes (clean stones up to several hundred carats), created renewed enthusiasm for this gemstone (Frazier and Frazier, 1997). During the decade, commercial quantities of small pieces of peridot were recovered in Vietnam.

QUARTZ

The most significant amethyst-producing countries are first Brazil and then Uruguay, as well as Tanzania, Namibia, and Zambia. Although amethyst remains one of the most important commercial gems, the market for natural amethyst has been undermined by the widespread infiltration of synthetic amethyst. Much of this synthetic material can be separated from natural amethyst, but this often requires advanced gemological testing. As the cost of such testing often exceeds the value of the amethyst, widespread availability of the synthetic material has depressed the value of the natural gem.

Figure 15. Myanmar remains the world's only commercial source of fine jadeite. These exquisite fern leaf carvings show the saturated color and semi-transparency commonly associated with "Imperial" jadeite. The larger carving measures 57.11 × 28.87 × 3.59 mm; photo © Tino Hammid and Christie's Hong Kong.

Figure 16. Most gem opal, such as the black opal shown in this pendant, comes from Australia. The opal is set within carved aquamarine. Jewelry designed and created by Kreg Scully; photo © Jeff Scovil.

Figure 17. Commercial quantities of peridot became available in relatively large sizes from a new deposit in Pakistan. The faceted stone shown here weighs 172.53 ct, and the crystal is 6 cm tall. Courtesy of Pala International; photo © Jeff Scovil.

Figure 18. During the 1990s, fine amethyst, citrine, and ametrine (here, 21.88–66.91 ct) were recovered from the Anahí mine in Bolivia. Courtesy of Minerales y Metales del Oriente; photo by Robert Weldon.

Figure 19. Myanmar remained an important source of spinel such as this 3.2-cm-tall crystal and 7.38 ct oval brilliant. Courtesy of Barker & Co.; photo © Jeff Scovil.

Most citrine comes from Brazil; some is produced by the heat treatment of amethyst. Sporadic mining of ametrine (bicolored amethyst-citrine; figure 18) from Bolivia continued in the early and mid-1990s, but the quantity and quality of the material declined at the end of the decade (C. Marcusson, pers. comm., 2000).

SPINEL

Although increasing in consumer recognition and demand, spinel remains overshadowed in the marketplace by other colored gems such as ruby and pink sapphire. During the '90s, spinel was mined from traditional localities in Sri Lanka and Myanmar (figure 19), as well as by the reworking of historic sources such as in the Pamir Mountains of Tajikistan.

The most important new sources were Tunduru in southern Tanzania and Ilakaka in Madagascar. These have produced primarily smaller stones (0.5–1.5 ct) in many pastel colors. Spinel was also found in Vietnam as a byproduct of ruby and sapphire mining. Today, spinel is growing in popularity due to its attractive colors, high clarity, good durability, and the fact that it is not treated.

TANZANITE

Tanzania's Merelani area remains the only commercial source of tanzanite (figure 20). In the 1990s, tanzanite approached emerald, ruby, and sapphire in popularity in the U.S., but was in less demand elsewhere. Its single source, rich color, and availability in larger sizes made this gemstone a mainstay in some jewelry stores. Enormous fluctuations in production, and therefore also in price, eventually led to an oversupply on the market in the latter half of the decade. However, a disastrous mine accident in 1998 forced the Tanzanian government to impose restrictions on tanzanite mining. Subsequently, the reduced mining (also due to increased costs), the difficulty of recovering material from ever-greater depths, and the departure of miners to new gem-producing areas in southern Tanzania all combined to elevate the price of this unique gemstone close to levels attained in the early 1990s (Bertoldi, 1998; box A).

Merelani also has produced the rarer green zoisite, which is colored by chromium (Barot and Boehm, 1992). Recent discoveries of transparent pink and bicolored—pink and yellow—zoisite (Wentzell, 2000) may provide new insight into the geology of the Merelani area.

TOPAZ

As it has for many years, topaz came from Brazil (figure 21), Nigeria, Pakistan, Sri Lanka, and the Ural Mountains in Russia. Pink-to-orange "Imperial" topaz enjoyed a rise in price throughout the 1990s, due to controlled supply in Brazil and minimal production in Pakistan (Drucker, 1997; see also box A). One dramatic development was the decline in demand for irradiated blue topaz, for which much near-colorless topaz had been mined in the 1980s. Natural-color blue topaz was not commercially available during the '90s.

TOURMALINE

Because it occurs in large, often high-clarity crystals of almost every color, tourmaline remains one of the most popular colored stones. The past decade saw further mining at many Brazilian pegmatites, and increased production in many African countries including Nigeria, Zambia, Mozambique, Madagascar, Tanzania, and Kenya. Afghanistan continued to yield "pastel" pink and green stones, in addition to blue and bicolored material.

Irradiation of colorless to light pink tourmaline supplied significant amounts of deep pink to red material in the early to mid-1990s. During this decade, the bright blue, green, and purple tourmalines from Paraíba, Brazil (figure 22) reached record retail prices (one of the authors [WFL] sold a 4.49 ct blue stone for $16,000/ct [see photo on accompanying Gem Localities chart]) due to very limited availability and high demand (Drucker, 1997). In the mid-1990s, enormous quantities (tons) of bicolored and brownish pink material came from the Morro Redondo mine in Minas Gerais, Brazil. Blue-green tourmaline has been available from several deposits in Namibia. The last few years saw even larger quantities of attractive pink-to-red tourmaline from Nigeria (Schmetzer, 1999a; figure 23), but the deposits are now apparently exhausted (M. Diallo, pers. comm., 2000). The influx of this material onto the gem market also caused a significant decline in the price of rough red and pink tourmaline.

OTHER GEM MATERIALS AND NEW LOCALITIES

A number of other gem materials from various localities became available during the 1990s (see table 2; figure 24). Blue to green **apatite** from Madagascar was used as a substitute for the similarly colored tourmaline from Paraíba, Brazil. At the **Benitoite** Gem mine in California, an important extension of the historic deposit was found in 1997, and resulted in a small production of this material. The past decade witnessed the increasing availability of **charoite** from Siberia as an ornamental gem material, as well as the marketing of **chrome diopside** (Costanza, 1998a). Gem varieties of **feldspar** came

Figure 20. The world's only commercial source of tanzanite remained the Merelani area of Tanzania. The tanzanite in the diamond pendant weighs 22.60 ct, and the loose stones range from 4.54 to 22.26 ct. Courtesy of The Collector Fine Jewelry; photo © Harold & Erica Van Pelt.

Figure 21. Like jadeite and tanzanite, commercial deposits of Imperial topaz (here, set stone about 6 ct, and loose stone, 3.82 ct) are found in a single area of the world—in this case, near Ouro Prêto, Minas Gerais, Brazil. Jewelry courtesy of Suwa & Son; photo by Maha Tannous.

Figure 22. Brightly colored tourmaline from Paraíba, Brazil, commanded record prices in the second half of the 1990s due to its rarity and strong market demand. Courtesy of Karl Egon Wild; photo © Harold & Erica Van Pelt.

from various localities (such as India, Canada, and the U.S.), with the most popular being those that exhibited optical phenomena (i.e., moonstone, sunstone, peristerite, and labradorite). However, significant quantities of transparent sunstone also came onto the market. **Iolite** provided an inexpensive substitute for blue sapphire and tanzanite, and was mined in Canada, India, Sri Lanka, and Madagascar. **Maw sit sit**, from the famous jade mining region in Myanmar, became more available in the mid-1990s. Several hundred kilograms were recovered between 1995 and 1997, although supplies diminished toward the end of the decade. In the early 1990s, some of the world's finest **rhodochrosite** began being recovered from the Sweet Home mine near Alma, Colorado, through the application of innovative mining and exploration techniques (Lees, 1998).

Gem **scapolite** came from localities in Myanmar, Sri Lanka, Tanzania, Tajikistan, and China. **Sphene** was found in a number of countries, sometimes in important quantities from deposits in Brazil and Madagascar. In general, the availability and quality of **sugilite** from South Africa declined during the past decade, but small pieces of high-quality material were commonly inlaid together with other gem materials in jewelry (G. Stockton, pers. comm., 2000). Finally, **zircon** provided an inexpensive alternative to fancy-colored diamonds, and was produced in Australia, Southeast Asia, Sri Lanka, and East Africa. With the broader audiences reached by televised home shopping programs worldwide, as well as the Internet, many of these more unusual gem materials became familiar to—and embraced by—more consumers than ever before.

PEARLS

The 1990s may well be remembered as the most significant "pearl era" in modern history. Not only has production of cultured pearls increased dramatically, but the variety available has grown as well. Of particular note were "pink rosé" and white Chinese Akoya cultured pearls; numerous colors of Chinese freshwater cultured pearls; black Tahitian (French Polynesia), white South Sea (Australia), and "golden" cultured pearls from Indonesia and the Philippines; purple and green New Zealand and Pacific Coast cultured abalone mabes; and pink conch "pearls" from the Caribbean, and pink and orange *Melo* "pearls" from Southeast Asia. According to N. Paspaley (pers. comm., 2000), the cultured pearls being harvested today are among the finest ever produced in terms of quality, size, quantity, and possibly value. Never has more been understood about the biology, habitat, sources, and

Figure 23. At the end of the decade, large quantities of gem-quality pink-to-red tourmaline were found near Ogbomosho, Nigeria. These crystals and nodules of tourmaline were among the initial production; the cut stone weighs 15.0 ct. Courtesy of Pala International; photo by Robert Weldon.

Figure 24. A variety of less familiar gem materials were commercially produced during the 1990s. Shown here (from left to right) are: top—Malagasy sphene (29.17 ct), Burmese scapolite (59.95 ct), Indian iolite (19.74 ct); bottom—American benitoite (3.09 ct), Cambodian zircon (13.37 ct), Peruvian rhodochrosite (6.22 ct), and Malagasy apatite (4.07 ct). Courtesy of William Larson; photo © Harold & Erica Van Pelt.

growth and harvesting conditions of pearls worldwide (Akamatsu, 1999).

Compared to cultured pearls, natural pearls remained exceedingly rare, but demand by some consumers is driving a global effort to recover them (K. C. Bell, pers. comm., 2000). This will remain a small but compelling part of the pearl industry.

Cultured Pearls. During the 1990s, the Japanese experienced a sharp decline in the production of Akoya cultured pearls and consequently in their dominance of the pearl market, although they expanded their influence as cultivators by helping pearl growers in other regions. The reduced number of cultured pearls from Japan (Muller, 1998) was offset by the increased production and popularity of cultured pearls from French Polynesia and Australia (figure 25), as well as Indonesia (figure 26), the Philippines, and China. The 1990s also witnessed the reemergence of several areas (such as Myanmar) that had declined earlier in the 20th century, due to overharvesting and environmental degradation (see table 3). Pearl culturing also increased in Vietnam (Bosshart et al., 1993; "Vietnam produces Akoya," 1999).

M. Coeroli (pers. comm., 2000) reports that the widespread popularity of black cultured pearls from French Polynesia followed the steady growth of pearl production, which increased 1,323% over the decade: from 575 kg of *Pinctada margaritifera* cultured pearls in 1990 to nearly 8.2 metric tons in 1999. Yet during this period, the number of pearl-producing farms in French Polynesia dropped from a high of 2,500 early in the decade to 1,076 at the last official count in 1998. Several smaller farms disappeared, while others expanded their farming area. As a result, fewer farms are cultivating more Tahitian pearls.

One of the interesting new trends was the production and use of "keshi" pearls. Once applied only to extremely small Akoya natural pearls, today *keshi* (from the Japanese word for poppy seed) is the common name for a nonnucleated cultured pearl produced by the oyster when the nucleus is rejected. Common byproducts of Australian and French Polynesian pearling operations, these baroque-shaped cultured pearls can reach up to 7–8 mm. By the mid-1990s, strands of such "keshis" were as popular as strands of round and semi-round cultured pearls (Federman, 1997), and their demand continued through the end of the decade (F. Mastoloni, pers. comm., 1999; M. Goebel, pers. comm., 2000).

According to N. Paspaley (pers. comm., 2000), successful pearl-farming techniques for South Sea pearl oysters (*Pinctada maxima*) were not developed until the 1980s. Since growth and harvesting can take up to eight years, noticeable achievements in production were not realized until the 1990s. Also during the '90s, new technology for the artificial propagation of the pearl oyster contributed to the increased production. Today, the Indonesian and Philippine pearl-culturing industries are completely dependent on hatcheries to supply the pearl oysters; only Australia and Myanmar have commercially important beds of natural *P. maxima* (N. Paspaley,

Figure 25. French Polynesia and Australia were the principal sources of black Tahitian and white South Sea cultured pearls, respectively. The cultured pearls in the necklaces shown here range from 11.69 to 16.21 mm (Tahitian) and 12.80 to 17.69 mm (South Sea). Photo © Tino Hammid and Christie's Hong Kong.

pers. comm., 2000; Themelis, 2000). Note that unlike other pearl oysters that easily can be bred in captivity, even artificially propagated *P. maxima* will grow to maturity only in their natural environment. Any future increase in pearl production from this region will largely be determined by the ability of pearl farmers to control pollution so they have favorable environmental conditions for the successful cultivation of hatchery-produced oysters.

Natural abalone pearls, still very rare, continued to be found sporadically in many localities (see table 3; figure 27). For the first time, successful production of cultured abalone mabes and a few whole cultured abalone pearls was realized in the 1990s (Fankboner, 1994). These came from abalone growers on the Pacific Coast of North America and in New Zealand. Mabes are more easily produced, and New Zealand cultured abalone mabes have appeared in commercial quantities since 1997 (Wentzell, 1998).

For freshwater cultured pearls, China clearly dominated the decade. Production of up to 1,200 metric tons is estimated for the year 2000 alone (A. Muller, pers. comm., 2000). Improved culturing techniques—using mantle-tissue nuclei—permitted the growth of large quantities of very attractive pearls, in large sizes, with remarkable roundness, and in a variety of uniform, natural-looking colors (figure 28). In years to come, China may also have a major effect on the market for bead-nucleated freshwater cultured pearls (Tao, 2000) if they succeed in expanding the availability of less-expensive round cultured pearls in sizes over 10 mm.

Pearl-culturing efforts in the southeastern U.S., led initially by John Latendresse of American Pearl Co. and later followed by James Peach of U.S. Pearl Co., produced a steady supply of freshwater cultured pearls throughout the decade, in creative shapes ranging from crosses to hearts and tabular forms (G. Latendresse, pers. comm., 2000). Also notable is the widespread incorporation of American shell-bead nuclei from the freshwater *Unio* mollusks for pearl culturing in most species. The U.S. exports to Japan an estimated $50 million annually in shells for making bead nuclei (Mayell, 1998). While today

Figure 26. At the Togian Islands in central Sulawesi, Indonesia, a pearl-oyster technician places a bead nucleus in the optimal location with the help of strong fiber-optic light. Photo by Andy Muller.

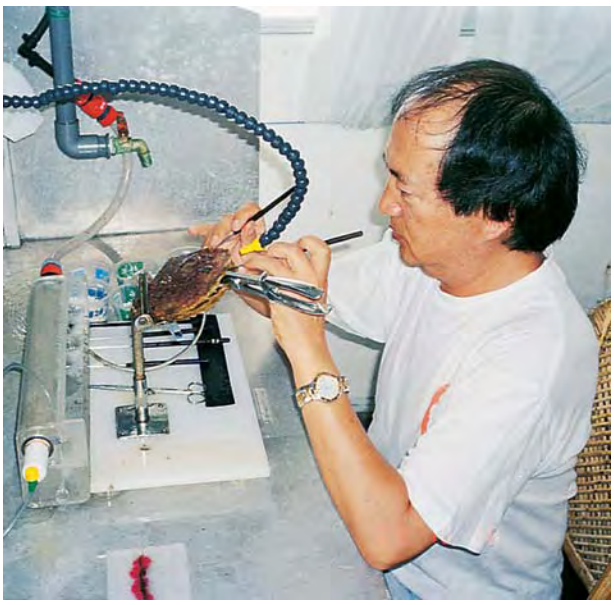

Figure 27. Because natural abalone pearls are so rare, considerable effort has been made to produce cultured abalone pearls. One of the success stories of the '90s was the introduction of commercial quantities of cultured abalone mabe pearls from New Zealand. The largest (natural) abalone pearl here weighs 77.75 ct. Courtesy of Tish and Wes Rankin, Pacific Coast Pearls; photo © Harold & Erica Van Pelt.

growers are testing other materials, most pearl culturers continue to use the *Unio* bead.

Unfortunately, American freshwater mollusks have become threatened by environmental problems caused by dam construction, silt from agriculture, water pollution, mining, industrial waste, and especially the introduction of an exotic bivalve—the zebra mussel (*Dreissens polymorpha*). The zebra mussel has no natural enemies, and is capable of outcompeting the roughly 300 species of pearl-producing freshwater mollusks remaining in U.S. rivers, streams, and lakes. Biologists estimate that 30% of the U.S. pearly species are already extinct, and 65% are endangered (Helfich et al., 1997).

Research and development in pearl-culturing technology led to significant discoveries during the past decade. In 1994, an international pearl conference and exposition was held in Hawaii that brought together—for the first time—pearl scientists, aquaculturists, government leaders, and pearl dealers (Sims and Fassler, 1994). Scientists reported the use of antibiotics and steroids to improve culturing success. Aquaculturists reviewed efforts to grow spat and introduce pearl-producing mollusks in areas (such as Hawaii) that had been overharvested at the turn of the century. Small operators in India were exploring freshwater bodies for pearl culturing. Speakers also discussed prospects for pearl-culturing industries in Mexico and Colombia. Interest in technical developments continues, and ongoing research is reported in journals such as *Aquaculture* and *Pearl Oyster Bulletin*.

Regional pearl associations emerged following the conference, and joined efforts by the World Pearl Congress to distribute newsletters via the Internet and promote pearls to the jeweler, as well as directly to the consumer, through the popular press. This, combined with exposure through movies and television programs, brought pearl fashion to the consumer internationally (M. Coeroli, pers. comm., 2000).

Calcareous Concretions. There was renewed interest in calcareous concretions, such as conch "pearls" from the Caribbean *Strombus gigas* and the new *Melo* "pearls" from Southeast Asia. In vogue at the turn of the 19th century, conch "pearls" regained popularity once their availability increased. They are recovered primarily from waters near the Bahamas, Bermuda, and Cuba (Fritsch and Misiorowski, 1987), as well as the southeastern U.S. (Shirai, 1994).

Early in the 1990s, small quantities of pink and orange calcareous concretions began to be reported

Figure 28. Toward the end of the decade, large, round cultured pearls from China (here, 9–11 mm in diameter) were available in significant quantities and a variety of colors. Courtesy of Rafco; photo by Robert Weldon.

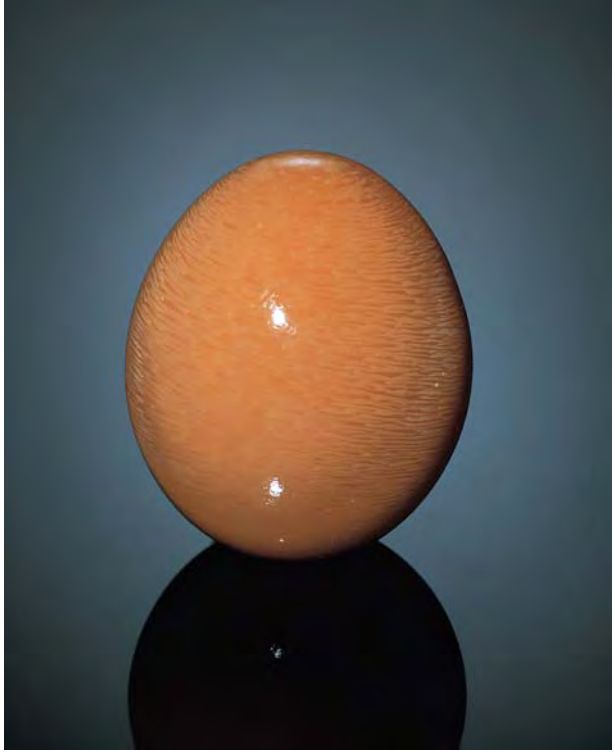

Figure 28. Calcareous concretions from the Melo *gastropod, which first appeared in the marketplace during the '90s, fetched record prices by the end of the decade. This 23.0 × 19.35 mm* Melo *"pearl" sold for $488,800 at the November 1999 Christie's jewelry auction in Hong Kong.*

from the *Melo* genus of the Bailer volutes, a spiral gastropod. They are harvested primarily from Southeast Asian waters, especially off the coasts of Vietnam (Jobbins, 1992; Scarratt, 1992; Zucker, 1999) and Myanmar (K. Scarratt, pers. comm., 2000). *Melo* "pearls" have also been reported from the South China Sea, India, Indonesia, and Malaysia (Shirai, 1994; K. Scarratt, pers. comm., 2000). At the November 1999 Christie's jewelry auction in Hong Kong, a 23.0 × 19.35 mm *Melo* "pearl" sold for US$488,800 (figure 28).

CONCLUSION AND FUTURE PROSPECTS

While for many gem materials most of the countries now considered important producers were identified by the 1970s, the discovery of new deposits within these countries, and even deposits in newly identified source countries, continued throughout the 1990s. Tanzania and Madagascar appeared to have the largest number of new gem deposits (see, e.g., Pezzotta, 1999). Vietnam (ruby and sapphire) and Nigeria (spessartine and tourmaline) also emerged as commercially important gem producers.

The past decade witnessed some exciting developments for the gem and jewelry industry. Diamonds were discovered in Canada, where no commercial diamond deposits had been known. The increased demand for colored stones, along with a better understanding of gem occurrences, has fueled greater exploration and recovery. Cultured pearls, once dominated by the round, white Japanese Akoyas, are now produced in an astonishing array of colors, qualities, and shapes from multiple geographic sources.

Sociopolitical conditions continued to play an important role in the 1990s. Predictions made by Shigley et al. (1990) for significant opening of Afghanistan, the former Soviet Union, and China have not yet come to pass due to the lack of infrastructure and capitalization. The discovery of major ruby deposits at Mong Hsu increased Myanmar's importance as a gem producer (Kammerling et al., 1994b), but military restrictions limit access to the area. Yet the greater freedom of trade in Vietnam has undoubtedly contributed to the discovery and exploitation of gem deposits there, especially ruby and sapphire.

Environmental concerns continued to influence both gem-mining and pearl-culturing activities. South Africa's Venetia mine, Australia's Argyle mine, and Canada's Ekati mine were each constructed to recover diamonds with state-of-the-art processing plants and extensive environmental controls. By contrast, at Canada's Diavik mine, a temporary denial of a crucial land permit for environmental reasons in 1999 resulted in the delay of mine development (Schuster, 2000). In the Ambondromifehy area of northern Madagascar, all sapphire mining was halted for several months of 1998 due to illegal digging in the Ankarana Special Reserve (Lurie, 1998). For cultured pearls, the greatest concern is water quality. At Ago Bay in Japan, some have blamed pollution from formalin—a liquid formaldehyde that the Japanese used to treat parasites in blowfish (Costanza, 1998b)—for the dramatic decline in the production of Akoya cultured pearls. Throughout the South Seas, instances of industrial development and destructive fishing practices threatened pearl production (D. Fiske, pers. comm., 2000).

Looking into the next decade, we predict the continued expansion of gem production in East Africa, Madagascar, and Southeast Asia, while Brazil and Myanmar remain important sources. New gems as well as new gem localities will undoubtedly be discovered, especially as remote areas become more accessible and technology advances.

TABLE 1. Gem localities of the 1990s for major gemstones.[a]

Gem material/locality	Reference
BERYL—Emerald	
◆ Africa	
Madagascar	
Fianarantsoa—**Mananjary**: *Ankadilalana, Infanadiana, Irondro, Morafeno* (7)	Schwarz and Henn (1992), Thomas (1993), Schwarz (1994)
Toliara—Ianapera (4)	Marchand (1995)
Mozambique	Malango and Taupitz (1996)
Nampula—Alto Ligonha (1)	Milisenda et al. (2000)
Zambezia—Morroa: *Maria* (6)	Thomas (1994)
Nigeria	
Kaduna—Gwantu	Kammerling et al. (1995g), Schwarz et al. (1996a)
Plateau—Janta, Rafin Gabas Hills, Sha Kaleri	Schwarz et al. (1996a)
Plateau—Jos	Lind et al. (1986)
Plateau—Nassarawan Eggon: *Kwafam Gwari*	Kammerling et al. (1995g), Schwarz et al. (1996a)
Tanzania	
Arusha—Lake Manyara: *Mayoka (Manyara)* (1)	Dirlam et al. (1992), Keller (1992)
Arusha—Ngorongoro: *Manghola* (13)	Suleman et al. (1994)
Rukwa—Sumbawanga (10)	Dirlam et al. (1992)
Zambia	
Copperbelt—**Kafubu**: *Chama, Dabwisa, Fibolele, Fwaya-Fwaya, Kamakanga, Kanchule, Libwente, Miku, Mitondo, Nkabashita, Pirala* (4)	Milisenda et al. (1999)
Zimbabwe	Kanis et al. (1991)
Matabelleland South—**Sandawana**: *Aeres, Machingwe, Orpheus, Zeus* (6); Zvishavane: *Mberengwa* (4)	Zwaan et al. (1997), Zwaan and Touret (2000)
Victoria—Bikita: *Chikwanda* (5); Masvingo: *Mayfield, Novello* (1)	
◆ Asia	
Afghanistan	
Parwan—**Panjshir Valley**: *Bakhi, Butak, Buzmal, Darun, Khenj, Mikeni* (5)	Bowersox et al. (1991), Bowersox and Chamberlin (1995)
India	
Andhra Pradesh—Srikakulam: *Kurupam* (30)	Panjikar (1995a)
Orissa—Balangir: *Kantabanji* (10)	Choudhuri and Gurachary (1993)
Rajasthan—Udaipur: *Kaliguman* (16)	S. Fernandes (pers. comm., 1999)
Tamil Nadu—Salem: *Sankari Taluka* (17)	Panjikar et al. (1997)
Pakistan	
Northwest Frontier—Mohmand: *Bucha* (5); **Swat River Valley**: *Charbagh, Gujar Killi, Makhad, Mingora, Shamozai* (4)	Arif et al. (1996), Aboosally (1999)
Russia	
Middle Ural Mountains—Malysheva, Takovaya: *Izumrudnie Kopi*	Schmetzer et al. (1991), Laskovenkov and Zhernakov (1995), Emlin (1996), Burlakov et al. (1997), Spiridonov (1998)
◆ Australia	Schwarz (1991a)
New South Wales—New England Range: *Emmaville, Torrington* (19)	Schmetzer (1994), Webb and Sutherland (1998)
Queensland—Mount Surprise (20)	Wilson (1995)
Western Australia—Pilbara: *McPhees Patch, Pilgangoora, Wodgina* (21); Poona: *Menzies, Poona* (2)	
◆ North America	
United States	
North Carolina—Mitchell: *Hiddenite*	Sinkankas (1997), Stone (1999)
◆ South America	
Brazil	Giuliani et al. (1990b, 1997)
Bahia—Anagé: *Açude, Juca, Lagoa Funda, Lagoinha, Piabanha, Pombas, Sossêgo* (14); Brumado (30); Campo Formoso: *Bica, Bode, Braúlio, Cabra, Formiga, Gavião, Lagarto, Marota, Trecho Novo, Trecho Velho* (5); **Carnaíba-Socotó**: *Arrozal, Carnaiba, Catuaba, Mundé, Socotó, Veio do Sebo* (5)	Schwarz et al. (1990), Couto (2000)
Ceará—Solonópole: *Coqui* (32); Tauá: *Boa Esperança* (31)	
Goiás—Itaberaí (35); Pirenópolis (33); **Porangatu**: *Mara Rosa, Pela Ema, Porangatu, Santa Terezinha* (34)	Pulz et al. (1998)
Minas Gerais—**Itabira**: *Belmont* (3); **Nova Era**: *Capoeirana* (3)	de Souza et al. (1992)
Tocantins—Araguaia: *Monte Santo* (41)	César-Mendes and Ferreira (1998), Johnson and Koivula (1998d)
Colombia	Giuliani et al. (1990a, 1995, 2000), Bosshart (1991), Schwarz (1991b, 1992), Branquet et al. (1999)
Boyacá—**Chivor**: *Buena Vista, Chivor, Las Vegas de San Juan (Gachalá), Mundo Nuevo, Somondoco* (3)	
Boyacá—**Muzo**: *Cosquez, El Chule, La Pita, Muzo, Peñas Blancas, Polveros, Santa Barbara, Tequendama* (1)	Ottaway et al. (1994), Johnson and Koivula (1996b), Johnson et al. (2000a)
BERYL—Aquamarine/ Heliodor/Morganite	
◆ Africa	
Kenya	
Eastern—Embu (2)	Barot et al. (1995)
Rift Valley—Baragoi: *Nachola* (3)	Keller (1992)
Madagascar	Henn et al. (1999b)
Antananarivo—Ankazobe (1); Betafo: *Anjanabonoina, Mahaiza, Tongafeno* (2); Soavinandriana (11)	Pezzotta (1999)
Antananarivo—Sahatany Valley: *Ibity, Manjaka, Tsilaizina* (3)	Lefevre and Thomas (1997), Pezzotta (1999)
Antsiranana—Andapa (19)	
Fianarantsoa—Ambositra (16), Fianarantsoa (51), Lac Itahy (18), Vondrozo (20)	Pezzotta (1999)
Mahajanga—Berere (5), Boriziny (40), Tsarantanana (6)	Pezzotta (1999)
Toamasina—Amboasary (14)	
Toliara—Tolanaro (21)	
Malawi	
Northern—Mzimba (1)	Milisenda et al. (2000)
Mozambique	Correia Neves (1987), Malango and Taupitz (1996)
Nampula—**Alto Ligonha**: *Macula* (1), *Muiane* (1); Monapo (2)	
Zambezia—Mocuba (3)	
Namibia	
Karibib—Usakos: *Spitzkoppe* (2)	Cairncross et al. (1998)
Nigeria	
Kaduna—Gwantu	Kammerling et al. (1995g)
Plateau—Jos	Lind et al. (1986)
Plateau—Nassarawan Eggon: *Sabon Wana, Tundun Delli*	Kammerling et al. (1995g), Schwarz et al. (1996a)
Plateau—Rafin Gabas Hills	Kanis and Harding (1990)
Plateau—Janta, Sha Kaleri	Schwarz et al. (1996a)
Tanzania	
Arusha—Loliondo (8), Longido (9)	Dirlam et al. (1992)
Dodoma—Kondoa (41)	A. Suleman (pers. comm., 1999)
Morogoro—Mvuha (30)	Dirlam et al. (1992)
Rukwa—Sumbawanga (10)	Dirlam et al. (1992)

[a] *This chart includes key producing localities of the decade, with references to publications in the contemporary literature. The country name is followed by the province/state/region, then the district, and finally the mine/deposit/occurrence name (in italics). Districts shown in bold were particularly important gem producers in the 1990s. Numbers in parentheses refer to locations plotted on the regional maps. Some countries are not shown on these maps, and therefore do not have any numbers indicated.*

Aquamarine-bearing pegmatites in Brazil have yielded some attractive crystals. This 12.6-cm-long aquamarine crystal, from the Teófilo Otoni region of Minas Gerais, shows both gemmy and opaque portions. Courtesy of Pala International; photo by Jeff Scovil.

Gem material/locality	Reference
Ruvuma—Nyamtumbo (42)	A. Suleman (pers. comm., 1999)
Singida—Singida (11)	Keller (1992)
Zambia	Milisenda et al. (2000)
Central—Kabwe: *Jagoda, Muchinga* (13)	
Eastern—Lukusuzi (6)	M. Sarosi (pers. comm., 1999)
Eastern—Lundazi: *Chama, Fwaya-Fwaya, Pela (Kapirinkesa)* (2)	Mambwe and Sikatali (1994)
Northern—Luangwa Valley (3)	
Western—Namwala: *Mumbwa, Namwala* (14)	
Zimbabwe	
Mashonaland North—Mwami–Karoi (2)	Shmakin and Wedepohl (1999), Milisenda et al. (2000)
◆ Asia	
Afghanistan	Bowersox and Chamberlin (1995)
Konar—Dhray-Pech, Gur Salak, Paprowk (2)	
Laghman—Mawi, Nilaw-Kolum (3)	
Nangarhar—Darre Nur (4)	
China	
Yunnan—Yuan Jiang: *Ailao Mountains*	More new finds... (1996)
India	
Gujarat—Panch Mahal: *Palikhanda* (11)	Panjikar (1996)
Jammu and Kashmir—Kargil: *Dangel, Padam* (12)	Panjikar (1994a)
Karnataka—Hassan: *Dodkadanur* (34); Mysore: *Melkote* (33)	S. Fernandes (pers. comm., 1999)
Madhya Pradesh—Ambikapur: *Newatola, Sapha* (31); Bastar: *Bhopalpatnam* (51); Raigarh: *Belghutri, Ginabahar* (38)	S. Fernandes (pers. comm., 1999)
Madhya Pradesh—Deobhog (19)	Jha et al. (1993)
Orissa—Balangir: *Ghuchepara, Saraibahal* (10)	Choudhuri and Gurachary (1993), Panjikar (1995b)
Orissa—Kalahandi: *Banjipadar, Sargiguda* (53)	S. Fernandes (pers. comm., 1999)
Orissa—Phulabani (13)	Current mining report... (1998)
Orissa—Sambalpur: *Bagdhapa, Charbati, Meghpal* (5)	Das (1993), Current mining report... (1998)
Rajasthan—Ajmer (14), Tonk (15), Udaipur (16)	Panjikar (1994b), Current mining report... (1998)
Tamil Nadu—Dindigul Anna: *Ayyalur, Sullerumbhu* (8)	S. Fernandes (pers. comm., 1999)
Tamil Nadu—Karur (54)	Boehm (2000)
Tamil Nadu—Salem (17)	J. Panjikar (pers. comm., 1999)
Kazakhastan	Smith and Smith (1995)
Qaraghandy—Balqash: *Kounradskiy*	
Qaraghandy—Taldyqorghan: *Aqshatau*	Spiridonov (1998)
Myanmar	
Mandalay—Mogok: *Ka-Baing, Sakangyi* (1)	Kammerling et al. (1994b)
Sagaing—Thazi: *Ye-bu* (7)	U Hlaing (pers. comm., 1999)
Nepal	Niedermayr (1992)
Bagmati—Kakani (1)	
Gandaki—Lamjung (2)	
Kosi—Ikuh Khola (3), Sankhuwasabha (4), Topke Gola (4)	
Mechi—Taplejung (4)	
Seti—Khaptad (5)	
Pakistan	
Northern Areas—Baltistan: *Dassu, Gone, Teston* (3)	Blauwet et al. (1997)
Northern Areas—Gilgit: *Buleche, Haramosh, Shengus* (2)	Blauwet et al. (1997)
Northwest Frontier—Chitral: *Garam Chashma* (1)	Khan (1986)
Russia	
Chita—Urchugan River	Spiridonov (1998)
Ekaterinburg—Asbest: *Shaytanka*	Emlin (1996), Spiridonov (1998)
Middle Ural Mountains—Mursinka–Adui: *Alabashka, Mursinka, Shaitanka, Yushakova*	Smith and Smith (1995), Emlin (1996)
Transbaikalia—Borzja: *Sherlova Gora*	Spiridonov (1998)
Sri Lanka	Dissanayake and Rupasinghe (1993), Milisenda and Henn (1999)
Central—Badulla: *Haputale* (18); Kegalla: *Avissawella* (9); Nuwara Eliya: *Kuruwitenna* (13), *Nawalapitiya* (29); Polonnaruwa: *Elahera* (8)	
Southern—Hambantota: *Lunugamwehera* (30); Kalutara: *Horana* (34); Matara: *Akuressa, Morawaka* (4); Monaragala: *Embilipitiya* (19), *Monaragala* (6), *Okkampitiya* (5); Ratnapura: *Balangoda* (2), *Kuruwita* (1), *Rakwana* (3), *Ratnapura* (1)	
Tajikistan	
Turkistan—Pamir Mountains: *Rangkul, near Murgab*	Skrigitil (1996), Spiridonov (1998)
Ukraine	Evseev (1994a)
Volyns'ka—Vladimir-Volnskiy	Koshil et al. (1991), Touret (1992)
Zhytomyr—**Zhytomyr**: *Volodarsk-Volnskiy*	Koivula et al. (1993b)
Vietnam	
Thanh Hoa—Thuong Xuan (1)	Ngu and Ngoc (1986)
◆ North America	
Canada	
British Columbia—Bennett: *Mount Foster*; McDame: *Horseshoe Ranch*; Passmore: *B-Q Claims*	Wilson (1999)
United States	Jacobsen (1993), Sinkankas (1997)
California—Pala: *Elizabeth R, White Queen*	
Colorado—Chaffee: *Mount Antero*	
Idaho—Sawtooth Mountains	
Maine—Oxford-Sagadahoc: *Bennett Quarry, Oxford,*	

Gem material/locality	Reference
Stoneham, Topsham	
New Hampshire—Grafton: *Grafton*; Sullivan-Cheshire: *Keene*	
◆ South America	
Brazil	Cassedanne and Alves (1991, 1992)
Bahia—Alcobaça: *Juerana* (20); Itambé: *Morro da Gloria, Paraíso* (24); Itanhém: *Jaqueto* (20); Macarani: *Lajedinho* (13); Maiquinique: *Jagarauna* (13); Vitória de Conquista: *Cercadinho* (14)	Cassedanne and Alves (1994), Couto (2000)
Ceará—Icó: *Serrote* (32)	Cassedanne and Alves (1994)
Espírito Santo—Baixo Guandu: *Santa Cruz (Itapina)* (16); Castelo: *Forno Grande* (15); Itaguaçu: *Bôa Vista* (16); Mimoso do Sul: *Concórdia* (15); Muqui: *São Domingos* (15); Pancas (16)	Cassedanne and Alves (1994)
Minas Gerais—**Jequitinhonha River Valley**: *Coronel Murta*, *Frade, Ilha Alegre, Laranjeiras, Manuel Silva* (18); Marambaia: *Coroa de Ouro, Galvão, Mucaia, Papamel* (22); **Mucuri River Valley**: *Marta Rocha* (22); Padre Paraíso (22);Pedra Azul: *Fortaleza, Medina, Pavão* (18); Salinas River Valley: *Bananal*, *Salinas* (18); Santa Cruz River Valley: *Três Barras, Urubu* (22); **Santa Maria de Itabira**: *Barro Prêto, Funil, Jatobá, Ponte da Raiz, Ribeirão Passa Bem, Tatu* (3); Sapucaia do Norte: *Sapucaia* (8)	Cassedanne and Alves (1994)
Paraíba—Frei Martinho: *Alto Quixaba* (24); Pedra Lavrada: *Alto das Flechas* (10)	R. Wegner and O. Moura (pers. comm., 2000)
Paraíba—Taperoá: *Pitombeira* (21)	Cassedanne and Alves (1994)
Rio Grande do Norte—Parelhas: *Carnaubinha* (10)	R. Wegner and O. Moura (pers. comm., 2000)
Rio Grande do Norte—Santa Cruz: *Gameleira* (10); *Tenente Ananias* (36)	Cassedanne and Alves (1994)
CHRYSOBERYL (Including cat's-eye)	
◆ Africa	
Madagascar	Henn et al. (1999b)
Antananarivo—Ankazobe (1)	
Fianarantsoa—Ambositra (16)	
Fianarantsoa—**Ilakaka–Sakaraha** (23)	Hänni (1999)
Toamasina—Ambatondrazaka (22)	Pezzotta (1999)
Tanzania	
Arusha—Lake Manyara: *Mayoka (Manyara)* (1)	Dirlam et al. (1992)
Ruvuma—**Tunduru**: *Muhuwesi River* (2)	Milisenda et al. (1997)
◆ Asia	
India	
Andhra Pradesh—Araku Valley (42); Khaman (1)	Current mining report... (1998)
Andhra Pradesh—Nellore (18)	J. Panjikar (pers. comm., 1999)
Andhra Pradesh—**Vishakhapatnam**: *Narsipatnam* (3)	Panjikar and Ramchrandran (1997), Current mining report... (1998), Kasipathi et al. (1999)
Kerala—Trivandrum (9)	Menon et al. (1994), Rajesh-Chandran et al. (1996)
Madhya Pradesh—Deobhog: *Jagdalpur, Mainpur* (19)	Jha et al. (1993)
Orissa—**Balangir**: *Jerapani, Sarapali* (10)	Choudhuri and Gurachary (1993), Panjikar and Ramchrandran (1997)
Orissa—Boudh: *Boudh, Ramgarh* (13); Kalahandi: *Sirjapali, Tundla* (53); Phulabani: *Belghar* (13); Rayagada: *Hatamuniguda, Karlagati, Paikdakul-gudu* (30)	S. Fernandes (pers. comm., 1999)
Orissa—Ranigurha: *Dakalguda* (57)	Panjikar and Ramchrandran (1997)
Orissa—Sinapali (21)	Viswanatha (1982)
Tamil Nadu—Dindigul–Anna: *Dharapuram* (8); Karur (54); Madurai: *Oddanchattram* (7)	Viswanatha (1982), Current mining report... (1998)
Tamil Nadu—Kanyakumari–Tirunelveli: *Arumanai, Karakonam, Midolam, Polukal* (6)	S. Fernandes (pers. comm., 1999)
Myanmar	
Mandalay—Mogok (1)	Hughes (1997)
Sri Lanka	Dissanayake and Rupasinghe (1993), Milisenda and Henn (1999)
Central—Badulla: *Haputale* (18); Kegalla: *Avissawella* (9); Nuwara Eliya: *Kuruwitenna* (13); Polonnaruwa: *Elahera, Kaluganga Valley, Laggola* (8)	
Southern—Galle: *Galle* (12); Hambontota: *Ambalantota* (11); Kalutara: *Alutgama* (10), *Horana* (34); Matara: *Akuressa* (4), *Deniyaya* (31); Monaragala: *Embilipitiya* (19); **Ratnapura**: *Balangoda* (2), *Pelmadulla* (1), *Rakwana* (3), *Ratnapura* (1), *Walawe* (1)	
◆ Australia	
Western Australia—Dowerin (13)	Bevan and Downes (1997)
◆ South America	
Brazil	Cassedanne and Roditi (1993)
Espírito Santo—Colatina: *Córrego Alegre* (16)	
Minas Gerais—Malacacheta: *Córrego do Fogo* (19); Padre Paraíso: *Americana River Valley, Santana River Valley* (22)	
CHRYSOBERYL—Alexandrite	
◆ Africa	
Madagascar	
Fianarantsoa—Ambodibakoly: *Kianjavato* (24)	D. Grondin (pers. comm., 1996)
Fianarantsoa—**Ilakaka–Sakaraha** (23)	Hänni (1999), Henn et al. (1999b)
Tanzania	
Arusha—Lake Manyara: *Mayoka (Manyara)* (1)	Dirlam et al. (1992), Keller (1992), Barot et al. (1995)
Lindi—Liwale, Nguhumahinga River (43)	H. Krupp (pers. comm., 1999)
Mtwara—Masasi: *Nachingwea* (20)	A. Suleman (pers. comm., 1999)
Ruvuma—**Tunduru**: *Muhuwesi River* (2)	Milisenda et al. (1997), Burford (1998)
◆ Asia	
India	
Andhra Pradesh—Araku Valley (42), Khaman (1), Krishna River (2)	Current mining report... (1998)
Andhra Pradesh—Vishakhapatnam: *Narsipatnam* (3)	Panjikar and Ramchrandran (1997), Kasipathi et al. (1999)
Kerala—Travancore: *Arvikkara* (69)	Viswanatha (1982), Menon et al. (1994), Current mining report... (1998)
Madhya Pradesh—Deobhog: *Latapara, Mainpur, Matrapara, Sendmuda* (19) (1997)	Jha et al. (1993), Panjikar and Ramchrandran
Orissa—Balangir: *Sarapali* (10)	Current mining report... (1998)
Orissa—Kalahandi: *Siminiguda* (53); Subarnapur: *Sonepur* (10)	S. Fernandes (pers.comm., 1999)
Orissa—Ranigurha: *Dakalguda* (57), Sambalpur: *Meghpal Ranchipada* (5)	Patnaik and Nayak (1993)
Tamil Nadu—Dindigul–Anna: *Dharapuram* (8); Kangayam(54); Kanyakumari (6); Karur (54); Madurai: *Oddanchattram* (7); Palni (55)	Current mining report...(1998), Viswanatha (1982)
Russia	
Middle Ural Mountains—Asbest, Malysheva: *Izumrudnie Kopi*	Evseev (1993b), Smith and Smith (1995), Emlin (1996), Burlakov et al. (1997)
Sri Lanka	
Southern—Matara: *Akuressa*, *Morawaka* (4); Ratnapura: *Eheliyagoda* (25), *Pelmadulla* (1), *Rakwana* (3), *Ratnapura* (1)	Milisenda and Henn (1999)
◆ South America	
Brazil	
Bahia—Carnaíba: *Carnaíba* (5)	Cassedanne and Roditi (1993)
Goiás—Porangatu: *Pela Ema* (34)	Pers. knowl. of author (GB)
Goiás—Uruaçú (17)	N. Haralyi (pers. comm., 1998)
Minas Gerais—**Antônio Dias**, Hematita, Santa Maria de Itabira (3)	Cassedanne and Roditi (1993)
Minas Gerais—Malacacheta: *Córrego do Fogo, Setubal River, Soturno River* (19)	Cassedanne and Roditi (1993)
CORUNDUM—Ruby	
◆ Africa	
Kenya	
Central—Thika: Chania River (6)	Keller (1992)

Gem material/locality	Reference
Coast—**Mangari**: *John Saul* (20)	Keller (1992), Emmett (1999b), Mercier et al. (1999a)
Coast—Taita Hills (7)	Barot et al. (1995)
Eastern—Kitui: *Taawajah* (8)	Barot and Harding (1994)
Rift Valley—West Pokot (16)	Keller (1992)
Madagascar	
Antananarivo—Antanifotsy (10)	Henn et al. (1999b), Pezzotta (1999)
Toliara—Ejeda (9), Gogogogo (8)	Henn et al. (1999b)
Toliara—Tolanaro: *Fotadrevo-Vohibory* (21)	Johnson and Koivula (1996f), Mercier et al. (1999b)
Malawi	
Southern—Chimwadzulu Hill (2)	Henn et al. (1990a), Emmett (2000)
Tanzania	
Arusha—Babati (23), Lake Manyara (1), Lelatema (3)	Dirlam et al. (1992)
Arusha—Longido: *Elkunulesilali, Lomwinyi, Mdarara, Olgira Hills* (9)	Dirlam et al. (1992), Keller (1992)
Arusha—Lossogonoi Hill (24)	Keller (1992), Suleman et al. (1994)
Arusha—Ngorongoro (13)	Bank and Henn (1988)
Dodoma—Kilosa (6), Mpwapwa (5)	Dirlam et al. (1992)
Kilimanjaro—Same (17)	Dirlam et al. (1992)
Lindi	
Morogoro—Gairo (25)	Keller (1992)
Morogoro—Luande (26), Mwarazi (29)	Suleman et al. (1994)
Morogoro—Magogoni (28), **Morogoro** (29), Mvuha (30)	Dirlam et al. (1992)
Morogoro—**Mahenge** (19)	Dirlam et al. (1992), Keller (1992)
Morogoro—**Matombo** (27)	Hänni and Schmetzer (1991), Keller (1992), Suleman et al. (1994)
Pwani—Ndundu (37)	Suleman et al. (1994)
Ruvuma—Songea: *Amanimakoro* (42); **Tunduru**: *Muhuwesi River* (2)	Henn and Milisenda (1997), Milisenda et al. (1997), Hamid et al. (1999)
Tanga—Handeni: *Kwachaga* (7)	Keller (1992), Suleman et al. (1994)
Tanga—Umba Valley (21)	Dirlam et al. (1992), Keller (1992)
Tanga—Usambara Mountains (21)	Barot et al. (1995)
◆ **Asia**	
Afghanistan	
Kabul—Jegdalek–Gandamak: *Mirkhalwat, Warmankai* (7)	Hughes (1994, 1997), Bowersox and Chamberlin (1995), Aboosally (1999), Bowersox et al. (2000)
Cambodia	
Battamberg—**Pailin**: *Phnum Ko Ngoap, Phnum O Tang, Phnum Yat, Samlot* (1)	Clark (1992), Hughes (1997)
China	Galibert and Hughes (1995)
Heilongjiang	
Qinghai	
Sichuan—Nanjiang	
Xinjiang—Kalpin	
Yunnan—Yuan Jiang: *Ailao Mountains*	
India	Hughes (1997)
Andhra Pradesh—Anantapur: *Hindupur, Kodegapali* (20); Guntur (56); Khaman: *Gobbugurti, Rangapur* (1); Warangal (43)	Current mining report... (1998)
Andhra Pradesh—Chittoor: *Polichettipalli, Yeracheruvupalli* (44); Nalgonda: *Lingampalli, Timmapur* (61)	S. Fernandes (pers. comm., 1999)
Andhra Pradesh—Vishakhapatnam (3)	Current mining report... (1998), Kasipathi et al. (1999)
Karnataka—Bellary (45); Chitradurga (47); Mandya: *Kollur* (48); Raichur (49); Shimoga (50)	Viswanatha (1982)
Karnataka—Chikmagalur (46); Hassan: *Nuggahalli* (34); Madikeri (60)	Viswanatha (1982), Current mining report... (1998)
Karnataka—Mysore: *Dughahalli, Ramanahalli* (33)	Viswanatha (1982), Choudhuri and Gurachary (1993), Current mining report... (1998)
Karnataka—Tumkur: *Pavugada, Sriangapura* (35)	S. Fernandes (pers. comm., 1999)
Madhya Pradesh—Bastar: *Bhopalpatnam* (51)	Current mining report...(1998)
Madhya Pradesh—Raipur: *Jagdalpur* (4); Sidhi: *Karkota, Pipra* (64)	S. Fernandes (pers. comm., 1999)
Orissa—Bagdihi (24); Sambalpur: *Meghpal, Ranchipada* (5)	S. Fernandes (pers. comm., 1999)
Orissa—Kalahandi: *Hinghilibahal, Jhillindghar* (53)	Panjikar (1997b)
Tamil Nadu—Kangayam (54); Karur: *Chinnadharapuram, Manvadi* (54); Madurai: *Kodaicanal, Oddanchattram* (7); Palni (55); Salem: *Chalasiramani, Dharampuri, Namakkal, Sitampundi* (17)	S. Fernandes (pers. comm., 1999)
Laos	
Annam Highlands—Ban Huai Sai (1)	Bosshart (1995), Kammerling et al. (1995c), Hughes (1997)
Myanmar	
Kachin—Lonkin: *Nanyaseik, Tanai* (15)	Kammerling et al. (1994b)
Kachin—Mansi: *Molo* (16)	U Hlaing (pers. comm., 1999)
Karen—Belin Thandaung (17)	Kammerling et al. (1994b)
Karen—Hlaingbwe River Valley: *Dawna Hills* (14)	Hlaing (1997)
Mandalay—**Mogok** (numerous deposits) (1)	Kane and Kammerling (1992), Kammerling et al. (1994b), Hughes (1997), Waltham (1999)
Sagaing—Madaya: *Sagyin Hills* (13)	Kammerling et al. (1994b)
Sagaing—Thabeitkyin: *Wa Byu Taung* (12)	U Hlaing (pers. comm., 1999)
Shan—Lai Hka: *Wan Ying* (8), Langhko: *Wan Hat* (10); Namhsan: *Nawarat* (9); Yawnghwe (11)	U Hlaing (pers. comm., 1999)
Shan—Momeik (Mong Mit) (2)	Kammerling et al. (1994b)
Shan—**Mong Hsu** (numerous deposits) (3)	Hlaing (1993, 1994), Smith and Surdez (1994), Smith (1995), Peretti et al. (1995, 1996), Hughes and Galibert (1999)
Nepal	
Gandaki—Ganesh Himal: *Dhading* (2)	Niedermayr (1992), Smith et al. (1997)
Pakistan	
Northern Areas—Hunza Valley (8)	Blauwet et al. (1997)
Northwest Frontier—Hari Parbat Mountains: *Nangimali* (10)	Rice (1996), Kane (1997)
Russia	
Polar Ural Mountains—Rai-Iz: *Makar-Ruz*	Shelton (1988), Spiridonov (1998)
Sri Lanka	Milisenda and Henn (1999)

At this open-pit ruby and sapphire mine near Mogok, Myanmar, portions of the original outcrop can still be seen near the "spirit house" in the center. Photo by Edward Boehm, March 1993.

Gem material/locality	Reference
Central—Nuwara Eliya: *Maskeliya* (15)	
Southern—Monaragala: *Embilipitiya* (19), *Okkampitiya* (5); Ratnapura: *Eheliyagoda* (25), *Pelmadulla* (1), *Rakwana* (3), *Ratnapura* (1)	
Tajikistan	
Turkistan—Pamir Mountains: *Nadezhda, Turakuloma*	Henn et al. (1990b), Smith (1998), Spiridonov (1998)
Turkistan—Pamir Mountains: *Rangkul, near Murgab*	Smith and Smith (1995)
Thailand	
Chanthaburi–Trat—Klung-Khao Saming: *Ba Waen, Bo I Rem, Bo Rai, Na Wong, Nong Bon, Tok Prom* (1)	Hughes (1997)
Vietnam	Kane et al. (1991), Kammerling et al. (1994a)
Nghe An—Bu Khang: *Quy Chau* (3)	
Yen Bai—**Luc Yen**: *Khoan Thong, Nuoc Ngap* (2)	Henn (1991)
◆ Australia	
New South Wales—Barrington (9)	Sutherland (1996), Sutherland and Coenraads (1996), Sutherland et al. (1999)

The fine sapphires in these earrings (approximately 16 ct each) are from Myanmar, and reportedly are untreated. Photo © Tino Hammid and Christie's Hong Kong.

CORUNDUM—Sapphire

◆ Africa	
Kenya	Keller (1992), Hughes (1997)
Central—Thika: *Chania River* (6)	
Eastern—Chandler's Falls: *Kubi Kano* (18); Garba Tula (17); Mtitio Andei: *Kinyiki Hill* (10)	
Rift Valley—Lodwar (5); Loldaika Hills: *Don Dol* (19); Maralal: *Samburu* (9); Murua Rith Hills, Pelekech Mountains (11); West Pokot (16)	
Madagascar	
Antananarivo—Antanifotsy (10)	Henn et al. (1999b), Pezzotta (1999)
Antsiranana—Ambilobe (12)	Pezzotta (1999)
Antsiranana—**Ambondromifehy**: *Amboud–rohefeha* (17)	Gonthier (1997), Superchi et al. (1997), Henn et al. (1999b), Schwarz et al. (2000)
Antsiranana—Milanoa (13)	Superchi et al. (1997), Pezzotta (1999), Laurs (2000)
Fianarantsoa—Andranolava (23)	Henricus (1999)
Fianarantsoa—**Ilakaka–Sakaraha** (23)	Hänni (1999), Henn et al. (1999a,b), Johnson et al. (1999b), Schmetzer (1999b), Laurs (2000)
Toliara—Amboasary (14), Bekily (26)	Henn et al. (1999b), Pezzotta (1999)
Toliara—**Andranondambo** (15)	Kiefert et al. (1996), Milisenda and Henn (1996), Schwarz et al. (1996b), Gübelin and Peretti (1997)
Toliara—Antsiermene (15)	Schwarz et al. (1996b)
Toliara—Betroka (27)	Koivula et al. (1992b), Henn et al. (1999b)
Malawi	
Southern—Chimwadzulu Hill (2)	Henn and Bank (1990), Henn et al. (1990a), Emmett (2000)
Nigeria	
Kaduna—Jemaa	Kanis and Harding (1990)
Mabila	Y. Melas (pers. comm., 2000)
Rwanda	
Cyangugu (1)	Krzemnicki et al. (1996)
Tanzania	
Morogoro—Magogoni (28), Mahenge (19), Mvuha (30)	Dirlam et al. (1992)
Morogoro—Matombo (27)	Keller (1992)
Ruvuma—**Songea**: *Amanimakoro* (42)	Suleman et al. (1994), Kammerling et al. (1996)
Ruvuma—**Tunduru** (2)	Suleman (1995), Henn and Milisenda (1997), Milisenda et al. (1997), Burford (1998)
Singida—Singida (11)	Keller (1992)
Tanga—Handeni (7), **Umba Valley** (21)	Dirlam et al. (1992), Keller (1992)
Tanga—Kalalani (21)	Seifert and Hyrsl (1999)
◆ Asia	
Afghanistan	
Kabul—Jegdalek–Gandamak (7)	Bowersox and Chamberlin (1995), Bowersox et al. (2000)
Cambodia	Hughes (1997)
Battambang—**Pailin**: *Phnum Ko Ngoap, Phnum O Tang, Phnum Yat* (1)	Ngu and Ngoc (1986), Sutherland et al. (1998)
Cardamom—Chamnop (3)	
Ratanakiri—Virochey: *Bo Kham, Bokeo, Voeune Sai* (2)	
Rovieng—Chamnom (4)	
China	Galibert and Hughes (1995)
Hainan—Penglai-Wenchang	
Heilongjiang—Mulan	
Jiangsu—**Fujian**: *Mingxi*; Liuhe	
Qinghai	
Shandong—Changle: *Wutu*	Guo et al. (1992)
Xinjiang Uygar—Taxkorgan	
India	Hughes (1997)
Andhra Pradesh—Anantapur (20), Kakinada (62), Nellore (18)	Viswanatha (1982)
Andhra Pradesh—Khaman (1)	Viswanatha (1982), Panjikar (1998)
Jammu and Kashmir—Kargil: *Soomjam* (12)	Hänni (1990), Panjikar (1997a), Current mining report... (1998)
Karnataka—Hassan (34), Kolar (32), Mysore (33), Tumkur (35)	Viswanatha (1982)
Kerala—Travancore (69)	Viswanatha (1982)
Kerala—Trivandrum (9)	Menon et al. (1994), Rajesh-Chandran et al. (1996)
Orissa—Kalahandi: *Banjipadar, Sargiguda* (53)	S. Fernandes (pers. comm., 1999)
Orissa—Nawapada: *Amera, Katamal* (63)	Patnaik (1993)
Tamil Nadu—Kangayam: *Chinnadharapuram, Malaipatti* (54)	S. Fernandes (pers. comm., 1999)
Kazakhstan	
Qaraghandy—Semizbugy	Shelton (1988)
Laos	
Annam Highlands—Ban Huai Sai (1)	Bosshart (1995), Kammerling et al. (1995c)
Myanmar	Hughes and Win (1995), Hughes (1997)
Kachin—Lonkin: *Nanyaseik* (15)	Kammerling et al. (1994b)
Kachin—Mansi: *Panhka* (16)	U Hlaing (pers. comm., 1999)
Mandalay—Mogok (numerous deposits) (1)	Kane and Kammerling (1992), Kammerling et al. (1994b)

Gem material/locality	Reference
Sagaing—Hlaingbwe River Valley: *Dawna Hills* (14); Singu: *Chaung-Gyi, New-Yan* (19); Thabeitkyin: *Kyauk Kyi, Kyauksaikan* (12)	U Hlaing (pers. comm., 1999)
Shan—Momeik (Mong Mit) (2)	Kammerling et al. (1994b)
Shan—Mong Hkak: *Mong Hkak, Mong Hynin* (18)	Hlaing (1993), Kammerling et al. (1994b)
Shan—Mong Hsak: *Mong Hsak River* (28); Mong Hsu: *Wan Kan* (3)	U Hlaing (pers. comm., 1999)
Nepal	
Gandaki—Ganesh Himal: *Dhading* (2)	Smith et al. (1997)
Russia	
Far East—Primorski Krai: *Kedrovka*	Y. Shelementiev (pers. comm., 1999)
Sri Lanka	Dissanayake and Rupasinghe (1993), Milisenda and Henn (1999), E.G. Zoysa (pers. comm., 1999)
Central—Badulla: *Bibile* (33), *Haputale* (18), *Koslanda* (18), *Lunugala* (33), *Passara* (16); Kegalla: *Avissawella* (9); Matale: *Matale* (7); Nuwara Eliya: *Hatton* (15), *Kuruwitenna* (13), *Maskeliya* (15), *Nawalapitiya* (29), *Nuwara Eliya* (22), *Talawakele* (15); Polonnaruwa: *Elahera* (8), *Kalahagala* (14), *Kaluganga Valley* (8)	
Southern—Hambantota: *Ambalantota, Ridiyagama* (11); Kalutara: *Alutgama* (10), *Horana* (34); Matara: *Akuressa, Morawaka* (4); Monaragala: *Amarawewa* (17), *Embilipitiya* (19), *Kataragama* (17), *Kochchikatana* (17), *Kochipatana* (6), *Monaragala* (6), *Okkampitiya* (5); **Ratnapura**: *Balangoda* (2), *Eheliyagoda* (25), *Kiriella, Nivitigala, Pelmadulla* (1), *Rakwana* (3), *Ratnapura* (1)	
Tajikistan	
Turkistan—Pamir Mountains: *Turakuloma*	Smith (1998)
Thailand	Hughes (1997)
Chanthaburi—Tha Mai: *Bang Kha Cha, Khao Ploi Waen, Khao Wao* (1)	
Chanthaburi–Trat—Klung-Khao Saming: *Bo I Rem* (1)	
Kanchanaburi—Bo Phloi: *Ban Chang Dan, Bo Phloi* (2)	Schlüssel (1991)
Phetchabun—Wichian-Buri: Ban *Khok Samran, Ban Marp Samo, Khlong Yang* (3)	
Phrae—Denchai–Wang Chin: *Ban Bo Kaeo, Huai Mae Sung* (4)	Vichit (1992)
Sukothai—Si Satchanalai: *Ban Huai Po, Ban Pak Sin, Ban Sam Saen* (6)	
Ubon Ratchanthani–Si Sa Ket—Nam Yun–Kantharalak (5)	
Vietnam	Kane et al. (1991), Hughes (1997)
Binh Thuan—Phan Thiet: *Da Ban, Ma Lam* (4)	Smith et al. (1995)
Dong Nai—Xa Gia Kiem: *Gia Kiem, Sau Le, Tien Co, Xa Vo* (5)	
Lam Dong—Di Linh: *Binh Dien, Di Linh* (6)	Smith et al. (1995)
Nghe An—Bu Khang: *Bu Khang, Qui Hoop, Quy Chau* (3)	Kammerling et al. (1994a)
Thanh Hoa—Xuan Le: *Thong Luan* (3)	
Yen Bai—Luc Yen: *Hin Om, Khau Sum, Khoan Thong, Lung Thin, Nuoc Lonh, Nuoc Ngap, Phai Chep* (2)	Kammerling et al. (1994a)
◆ Australia	
New South Wales—Barrington (9)	Sutherland and Coenraads (1996), Webb (1997), Sutherland et al. (1998, 1999)
New South Wales—**New England Range**: *Glen Innes, Inverell* (10)	Oakes et al. (1996), Sutherland (1996), Hughes (1997), Aboosally (1998), Neville and von Gnielinski (1999), Sutherland et al. (1999)
New South Wales—Oberon: *Vulcan State Forest* (11)	F. L. Sutherland (pers. comm., 1999)
Queensland—**Anakie–Rubyvale**: *Anakie* (31)	Duffy (1995), Wilson (1995), Aboosally (1998), Neville and von Gnielinski (1999)
Queensland—Lava Plains (30)	Neville and von Gnielinski (1999)
◆ North America	
Canada	Wight (1999a)
British Columbia—Slocan Valley: *Passmore (Blu Moon, Blu Starr, Sapphire Hill)*	Wilson (1999), Coenraads and Laird (2000)
Labrador	
United States	Hughes (1997)
Montana—Deer Lodge: *Dry Cottonwood Creek*	Hughes (1995)
Montana—**Granite**: *Rock Creek*	Emmett and Douthit (1993)
Montana—**Judith**: *Yogo Gulch*	Allen (1991), Mychaluk (1995)
Montana—Lewis and Clark (along Missouri River): *American Bar, Dana Bar, Eldorado Bar, Emerald Bar, French Bar, Magpie Gulch, Metropolitan Bar, Spokane Bar*	Sinkankas (1997)
◆ South America	
Brazil	
Minas Gerais—Indaiá (18)	Epstein et al. (1994), Henn et al. (1994)
Colombia	
Cauca—Mercaderes (2)	Johnson et al. (2000b)
DIAMOND	
◆ Africa	
Angola	Levinson et al. (1992), Janse (1995)
Lunda Norte—**Andrada**: *Catuca (Catoca)* (3); Maxinje: *Cuango River* (2)	
Lunda Norte—**Andrada**: *Chitotolo* (3)	Ambroise (1998)
Lunda Norte—**Chicapa and Luachimo Rivers**: *Caixepa, Camafuca, Camagico, Camatchia, Camatue* (1)	Khar'kiv et al. (1992)
Malanje—Banano (4)	A. Janse (pers. comm., 1999)
Botswana	Janse (1995, 1996)
Central—**Orapa**: *Letlhakane, Orapa* (1)	Levinson et al. (1992), Duval et al. (1996)
Ghanzi—Ghanzi: *Gope* (4)	
Kweneng—**Jwaneng**: *Jwaneng* (2)	
Ngamiland—Tsodilo Hills (3)	A. Janse (pers. comm., 1999)
Central African Republic	Levinson et al. (1992), Janse (1995)
Haute-Kotto—Mouka Quadda	
Haute-Sangha—Berbérati-Carnot: *Mambere River*	Censier and Tourenq (1995)
Democratic Republic of the Congo (Zaire)	
Bandundu—Kwango (Cuango) River (1)	A. Janse (pers. comm., 1999)
Kasai Occidental—Tshikapa: *Kasai River* (2)	Janse (1995)
Kasai Oriental—Mbuji-Mayi: *Bushimaie River, Miba, Talala* (3)	Janse (1995)
Ghana	
Ashanti—Akwatia: *Birim River*	Levinson et al. (1992), Janse (1996), Stachel and Harris (1997)
Guinea	
Région Forestière—Baloue River Valley: *Trivalence*	Levinson et al. (1992), Janse (1996)
Région Forestière—Diani River Valley: *Aredor, Hymex*	A. Janse (pers. comm., 1999)
Côte d'Ivoire	Janse (1996)
Korhogo—Tortiya	
Seguela—Seguela	Levinson et al. (1992)
Mali	
Kayes—Kéniéba	Janse (1996)
Namibia	
Lüderitz—**Orange River**: *Auchas, Daberas* (4)	Janse (1995)
Lüderitz—**Oranjemund**: *Sperrgebiet (Elizabeth Bay, Namdeb, and other marine deposits)* (3)	Gurney et al. (1991), Levinson et al. (1992), Wannenburgh (1995), Duval et al. (1996)
Sierra Leone	
Eastern—Bafi and Sewa Rivers	Levinson et al. (1992), Duval et al. (1996), Janse (1996)
Eastern—Koidu: *Tongo*	A. Janse (pers. comm., 1999)
South Africa	Levinson et al. (1992)

Gem material/locality	Reference
Cape—**Kimberley**: *Barkley West, Bellsbank, Bultfontein, Dutoitspan, Kimberley, Wesselton* (2); Orange River: *Baken*; **Postmasburg**: *Finsch* (1)	Janse (1995, 1996)
Cape—**Namaqualand**: *Benguela, Kleinzee, and other marine deposits* (3)	Gurney et al. (1991), Levinson et al. (1992), Duval et al. (1996)
Orange Free State—**Koffiefontein**: Koffiefontein (4)	Janse (1995, 1996)
Orange Free State—Theunissen: *Star* (8)	A. Janse (pers. comm., 1999)
Transvaal—**Messina**: *Venetia* (6); **Pretoria**: *Marsfontein, Oaks, Premier* (5)	Janse (1995, 1996)
Tanzania	
Shinyanga—**Shinyanga**: *Mwadui (Williamson)* (12)	Dirlam et al. (1992), Levinson et al. (1992), Janse (1996)
Zimbabwe	
Matabeleland South—Limpopo River: *River Ranch* (3)	Duval et al. (1996)
◆ Asia	
China	Steiner (1997)
Hunan—Yuan River	R. Li (pers. comm., 1999)
Liaoning—Fuxian	Janse (1995)
Shandong—Mengyin: *Changma*	Dobbs et al. (1994)
Shandong–Jiangsu—Linshu (Xiazhuang)	A. Janse (pers. comm., 1999)
India	Babu (1998)
Andhra Pradesh—Anantapur: *Chigicherla-Gollapalle, Lattavaram, Vajrakurur* (20); Krishna: *Lower Krishna River Valley* (2); Kurnool: *Banganapalle, Middle Krishna River Valley, Munimadagu* (22); Mahbubnagar: *Kotakonda, Maddur* (23)	
Madhya Pradesh—Bastar: *Bhejripadar* (51), *Indravati River* (26), *Tokapal* (51); Raipur: *Bahradih, Jangra, Kodomali, Payalikhand* (4)	
Madhya Pradesh—Panna: *Hinota, Majhgawan* (25)	Chatterjee and Rao (1995)
Maharashtra—Garhchiroli (58)	Choudhuri and Gurachary (1993)
Orissa—Balangir: *Mahanadi River* (10)	Garlick (1993)
Orissa—Bhawanipatna (27)	J. Panjikar (pers. comm., 1999)
Orissa—Sambalpur: *Tel River* (5)	
Rajasthan—Chittaurgarh (28)	Choudhuri and Gurachary (1993)
Uttar Pradesh—Jungel Valley (59)	Viswanatha (1982)
Uttar Pradesh—Mirzapur (29)	Choudhuri and Gurachary (1993)
Indonesia	Levinson et al. (1992), Duval et al. (1996)
Borneo—Kalimantan, Selatan: *Martapura*; Tengah: *Maurateweh*	Janse and Sheahan (1995)
Borneo—Kalimantan-Barat: *Pontianak–Landak*	Spencer et al. (1988)
Myanmar	
Kachin—Lonkin: *Nanyaseik* (15)	Pers. knowl. of author (GB)
Kachin—Putao (4)	Kammerling et al. (1994b)
Kachin—Tanaing (20)	U Hlaing (pers. comm., 1999)
Pegu—Toungoo (21)	Hlaing (1990b), Kammerling et al. (1994b), Hlaing and Win (1997)
Shan—Momeik (Mong Mit): *Bo Dae, Kyeintaw, Mohawk* (2)	Hlaing (1990b), Kammerling et al. (1994b), Hlaing and Win (1997), pers. knowl. of author (GB)
Tenasserim—Taninthari River: *Theindaw* (5)	Hlaing (1990b), Kammerling et al. (1994b), Hlaing and Win (1997)
Tenasserim—Tavoy River (5)	Kammerling et al. (1994b)
Russia	Strand (1991), Spiridonov (1998)
Arkhangelsk—Zimniy Bereg: *Kepinskoye, Verkhotinskaya*	Possoukhova et al. (1999)
Arkhangelsk—Zimniy Bereg: *Zolotitskoye*	Smirnov (1993), Evseev (1994a), Sinitsyn et al. (1994), Yushkin (1996)
Middle Ural Mountains—Vischera River	Shelton (1988)
Yakutia (Sakha)—**Anabar**: *Kuonamka River*; **Nyurba**: *Botuobinskaya, Nurbunskaya*	A. Janse (pers. comm., 1999)
Yakutia (Sakha)—**Daldyn-Alakit**: *Aikhal, Krasnupresnenskaya, Sytakanskaya, Udachnaya, Yubileynaya, Zarnitsa*; **Malaya-Botuobiya**: *Internatsionalnaya, Mir, Sputnik*	Levinson et al. (1992), Duval et al. (1996)
◆ Australia	Levinson et al. (1992)
New South Wales—New England: *Bingara, Copeton* (14)	Barron et al. (1996), Meyer et al. (1997), Webb and Sutherland (1998)
Northern Territory—Battan: *Merlin* (18)	Jaques (1994), Lee et al. (1997, 1998)
Western Australia—Central Kimberley: *Aries* (16)	Edwards et al. (1992), Towie et al. (1994)
Western Australia—East Kimberley: **Argyle** (17)	Chapman et al. (1996), Pardon (1999)
Western Australia—East Kimberley: *Bow River* (17); North Kimberley: *Upper Bulgurri River* (12)	A. Janse (pers. comm., 1999)
Western Australia—West Kimberley: *Ellendale* (15)	Jaques (1994)
◆ North America	
Canada	
Northwest Territories—Lac de Gras: *Ekati*	Levinson et al. (1992), Pell (1994)
United States	
Arkansas—Pike: *Murfreesboro*	
Wyoming–Colorado—Fort Collins: *Kelsey Lake*	Johnson and Koivula (1996c), Hausel (1997), Sinkankas (1997)
◆ South America	
Brazil	
Mato Grosso—Alto Paraguai: *Nortelândia* (25)	Cassedanne (1989)
Mato Grosso—Aripuanã: *Juina* (25)	
Minas Gerais—Diamantina: *Campo do Sampaio, Datas, Extração, Guinda, São João da Chapada, Sopa* (26); Jequitai (27); Jequitinhonha River Valley: *Grão Mogol, Itacambira–Rio Macaúbas, Serro do Cabral* (18)	Cassedanne (1989), Karfunkel et al. (1994, 1996), N. Haralyi (pers. comm., 1998)
Minas Gerais—Triângulo Mineiro: *Abaeté River, Coromandel* (28)	Cassedanne (1989), Gonzaga et al. (1994), Karfunkel et al. (1994)
Pará—Tocantins River (6)	Cassedanne (1989)
Roraima—Branco River: *Tepequém* (29)	Meyer and McCallum (1993)
Guyana	Levinson et al. (1992), Meyer and McCallum (1993)
Cuyuni–Mazaruni—Cuyuni River, Mazaruni River (1)	
Potaro–Sirapuni—Potaro River (2)	
Venezuela	Levinson et al. (1992), Meyer and McCallum (1993), Heylmun (1994, 1995)
Bolívar—Caroní River (2), Cuyuní River (1), Paragua River (2)	
Bolívar—Guaniamo River: *Guaniamo, Quebrada River* (3)	Coenraads et al. (1994), Taylor (1999)

GARNET

◆ Africa

Eritrea	
Asmera—Sciumagalle	Milisenda and Hunziker (1999)
Ethiopia	
Sidamo—Chumba	Barot (1993)
Kenya	
Coast—Mgama-Mindi: *GG, Gitshure, Lualenyi, Minkeno, Scorpian* (21)	Kane et al. (1990), Keller (1992)
Coast—Taita Taveta (4)	Barot et al. (1995)
Rift Valley—Lodwar: *Lokirima* (5)	Barot (1993)
Madagascar	
Antananarivo—Betafo (2)	Henn et al. (1999b)
Antananarivo—Sahatany Valley (3)	Henn et al. (1999b), Pezzotta (1999)
Fianarantsoa—Ambositra (16), Ambovombe (28), Ihosy (29), Ranohira (23)	Henn et al. (1999b)
Fianarantsoa—**Ilakaka–Sakaraha** (23)	Hänni (1999), Henn et al. (1999b)
Mahajanga—Maevatanana (25)	Johnson and Koivula (1998h)
Mahajanga—Mahajanga (30)	Henn et al. (1999b), Pezzotta (1999)
Toamasina—Maralambo (31)	Johnson and Koivula (1998f)
Toliara—Ampanihy (32), Itrongay (43), Tolanaro (21)	Henn et al. (1999b)
Toliara—Bekily (26)	Henn (1999), Schmetzer and

Gem material/locality	Reference
	Bernhardt (1999)
Toliara—Betroka (27)	Henn et al. (1999b), Pezzotta (1999)
Toliara—Gogogogo (8)	Mercier et al. (1997)
Malawi	
Northern—Mzimba (1)	C. Hedegaard (pers. comm., 1998)
Mali	
Kayes—Diakon	Brightman and Tunzi (1995), Johnson et al. (1995), Lind et al. (1995), Johnson and Koivula (1997b, 1998e)
Mozambique	
Niassa—Cuamba (4)	Johnson and Koivula (1996d), Malango and Taupitz (1996), Bank et al. (1998)
Namibia	
Kaokoveld—**Hartmann Mountains**: *Kunene River* (6)	Koivula et al. (1993e), Lind et al. (1993), Kammerling et al. (1995d), Johnson and Koivula (1996h)
Karibib—Usakos: *Usakos* (8)	Johnson and Koivula (1997e)
Outjo—Damara Mountains (5)	Wenk (1997), Lind et al. (1998)
Nigeria	
Oyo—**Ogbomosho**: *Iseyin*	Milisenda and Zang (1999), Zang et al. (1999)
Tanzania	
Arusha—Kangala: *Loiborsoit* (14)	Suleman et al. (1994)
Arusha—Komolo: *Komolo* (14)	Keller (1992)
Arusha—Lelatema: *Lelatema Mountains* (3)	Dirlam et al. (1992), Keller (1992)
Arusha—Merelani (15)	Dirlam et al. (1992), Kane et al. (1991)
Arusha—Tiriti (31)	Dirlam et al. (1992), Suleman et al. (1994)
Dodoma—Mpwapwa (5)	Dirlam et al. (1992)
Kilimanjaro—Pare Mountains (16)	Keller (1992)
Kilimanjaro—Same: *Lemkuna* (17)	Dirlam et al. (1992)
Lindi—Lindi: *Luisenfelde, Nambunju* (18)	Keller (1992)
Lindi—Ruangwa (39)	McClure (1999)
Morogoro—Magogoni (28), Mahenge (19), Mvuha (30)	Dirlam et al. (1992)
Mtwara—Masasi: *Namaputa* (20)	Dirlam et al. (1992), Keller (1992)
Ruvuma—**Tunduru** (2)	Milisenda et al. (1997)
Tanga—Handeni (7)	A. Suleman (pers. comm., 1999)
Tanga—Kalalani (21)	Seifert and Hyrsl (1999)
Tanga—Umba Valley (21)	Dirlam et al. (1992), Keller (1992)
Tanga—Usambara Mountains (21)	Barot et al. (1995)
Zambia	
Central—Serenje (8)	Mambwe and Sikatali (1994)
Eastern—Lundazi (2)	Johnson et al. (1999c)
Eastern—Nyimba (7)	Mambwe and Sikatali (1994)
Southern—Gwembe (9); Mazabuka: *Nega Nega* (10)	Mambwe and Sikatali (1994)
◆ Asia	
Azerbaijan	
Caucasus Mountains—Dashkesan	Smith and Smith (1995), Spiridonov (1998)
China	
Jiangsu—Donghai	
Qinghai—Qui Lien Mountains	
Xinjiang Uygur—Altai Mountains: *Cocoktau, Qibeiling*	Wang and Liu (1994)
Yunnan	More new finds... (1996)
India	
Andhra Pradesh—Araku Valley (42)	S. Fernandes (pers. comm., 1999)
Andhra Pradesh—Khaman (1), Krishna River (2)	Viswanatha (1982)
Andhra Pradesh—Vishakhapatnam (3)	Viswanatha (1982), Kasipathi et al. (1999)
Karnataka—Hassan (34), Mysore (33)	Viswanatha (1982)
Kerala—Ernakulam (36), Travancore (69)	Viswanatha (1982)
Madhya Pradesh—Bastar: *Dampaya, Kuchnur* (51); Betul: *Bisighat, Chunabhuru* (52)	S. Fernandes (pers. comm., 1999)
Madhya Pradesh—Deobhog: *Jagdalpur* (19)	Jha et al. (1993)
Orissa—Angul: *Jhilli, Magarmuhan, Nuagaon* (37)	Das et al. (1993), Jha et al. (1993)
Orissa—Deogarh: *Jharposi* (5); Kalahandi: *Ghatpara, Singhjaran* (53); Nawapada: *Dhamjar, Sardhapur* (63); Subarnapur: *Naktamunda, Siali* (10)	Das et al. (1993), S. Fernandes (pers. comm., 1999)
Orissa—Sambalpur: *Bagdhapa, Meghpal* (5)	Das et al. (1993), Current mining report... (1998)
Rajasthan—Ajmer (14)	Viswanatha (1982), Current mining report... (1998)
Rajasthan—Bhilwara (39)	S. Fernandes (pers. comm., 1999)
Rajasthan—Chittaurgarh (28), Tonk (15)	Current mining report... (1998)
Rajasthan—Jaipur (40), Jodhpur (41), Udaipur (16)	Viswanatha (1982)
Tamil Nadu—Karur: *Manavadi* (54); Salem (17)	Viswanatha (1982)
Tamil Nadu—Madurai: *Oddanchattram* (7)	S. Fernandes (pers. comm., 1999)
Kazakhstan	
Qaraghandy	Shelton (1988), Evseev (1994a), Smith and Smith (1995)
Myanmar	Hughes (1997)
Kachin—Putao: *Sankawng* (4)	U Hlaing (pers. comm., 1999)
Kayah—Bawlake: *Bawlake River* (27)	U Hlaing (pers. comm., 1999)
Mandalay—Mogok: *Kyat-Pyin* (1)	Kammerling et al. (1994b)
Sagaing—Pyawbwe: *Pyawbwe East* (22)	U Hlaing (pers. comm., 1999)
Shan—Lai Hka (8), Mong Kang (23), Mong Mit (2), Namhkan (24)	U Hlaing (pers. comm., 1999)
Shan—Mong Hsak (28)	Hlaing and Win (1996)
Pakistan	Blauwet et al. (1997)
Northwest Frontier—Neelum Valley (9)	Henn (1996), Johnson and Koivula (1996g)
Northwest Frontier—Swat Valley: *Jambil* (4)	Jackson (1992)
Russia	
Far East—Chukot Peninsula: *Tavmatey*; Kamchatka Penninsula: *Chechatvayam*; Primorski Krai: *Dalnegorsk*	Smith and Smith (1995)
Far East—Primorski Krai: *Sinerechenskoye*	Evseev (1994a), Smith and Smith (1995)
Karelia—Lake Ladoga: *Kitelya*; Shuyeretskoye: *Terbe Island*	Evseev (1994b)
Middle Ural Mountains—Asbest: *Bazenovskoye*;	Smith and Smith (1995),

Nigeria became an important source of spessartine garnet (here, 5–13 ct) and rubellite tourmaline (5–25 ct) at the end of the decade. Courtesy of Pala International and Bill Barker Co.; photo by Robert Weldon.

Gem material/locality	Reference
Perm: *Saranovskoye*	Kolesar (1997)
Middle Ural Mountains—Nizhniy Tagil: *Bobrowka–Bolshaya Rivers*; Verhnij Ufalev: *Karkodino, Poldnevaya*	Shelton (1988), Evseev (1993a), Phillips and Talantsev (1996), Spiridonov (1998)
Siberia— Akhtaragda–Viluy Rivers: *Chernyshevsky*	Evseev (1994a), Smith and Smith (1995), Spiridonov (1998)
Southern Ural Mountains—Zlatoust: *Akhmatovskaya*	Evseev (1993a), Smith and Smith (1995)
Sri Lanka	Dissanayake and Rupasinghe (1993), Milisenda and Henn (1999)
Central—Badulla: *Haputale* (18), *Passara* (16); Kegalla: *Avissawella* (9); Nuwara Eliya: *Hatton* (15), *Kuruwitenna* (13), *Maskeliya* (15); Polonnaruwa: *Elahera, Kaluganga Valley* (8), *Kongahawela, Polonnaruwa* (14)	
Southern—Hambantota: *Ambalantota* (11), *Lunugamwehera, Paskema* (30), *Ridiyagama* (11); Kalutara: *Horana* (34); Matara: *Akuressa*, *Morawaka* (4); Monaragala: *Athiliwewa* (20), *Embilipitiya* (19), *Kataragama* (17), *Okkampitiya* (5); Ratnapura: *Balangoda* (2), *Rakwana* (3)	Johnson and Koivula (1996a, 1998a), Chandrajith et al. (1998)
Vietnam	
Yen Bai—Luc Yen (2)	Kammerling and Koivula (1994)
◆ Australia	
Northern Territory—Harts Range (3)	F. L. Sutherland (pers. comm., 1999)
◆ Europe	
Czech Republic	
Bohemia—Bohemian Hills: *Podsedice, Trebenice*	Schluter and Weitschat (1991), Korbel (1993)
◆ North America	
Canada	
British Columbia—McDame	Wilson (1999)
British Columbia—Slocan Valley: *Passmore*	Wight (1999b), Wilson (1999)
Quebec—Asbestos: *Jeffrey*	Sinkankas (1997)
Quebec—Black Lake	Johnson et al. (1999a), Wilson and Wight (1999)
United States	
Alaska—Wrangel: *Stikine River*	Frazier and Frazier (1990c)
California—Ramona: *Little Three*	Foord et al. (1989)
Idaho—Benewah: *Emerald Creek*	Sinkankas (1997)
◆ South America	
Brazil	
Minas Gerais—Galiléia: *Barra do Cuieté* (8)	Johnson and Koivula (1999b)
Minas Gerais—São José da Safira: *Poaia* (19)	R. Wegner and O. Moura (pers. comm., 2000)
Rio Grande do Norte—Carnaúba dos Dantas: *Pedra Bonita* (10)	R. Wegner and O. Moura (pers. comm., 2000)
Tocantins—Valério: *Balisto* (42)	Wegner et al. (1998)
JADE—Jadeite	
◆ Asia	
Japan	Koivula and Kammerling (1990)
Hyogo—Oya	Chihara (1999)
Niigata—Itoigawa: *Hashidate*	
Niigata—Omi: *Himekawa and Kotaki Rivers*	Chihara (1999)
Toyama—Asahi	
Kazakhastan	
Qaraghandy—Itmurundy	Spiridonov (1998)
Myanmar	Htein and Naing (1994, 1995), Kammerling et al. (1994b), Ward (1997), Galibert and Hughes (1999), Hughes et al. (2000)
Kachin—Hpakan: *Hpakan, Hpakangyi, Hwehka, Makapin, Maw-sisa, Sate Mu, Seng Tong, Tawmaw, Uru River* (15); Lonkin (15)	Ou Yang (1999)
Kachin—Laisai (26), Mawhun (25)	
Sagaing—Hkamti: *Nansibon, Natmaw* (6)	
Russia	
Polar Ural Mountains—Rai-Iz: *Karovoye*; Syum-Keu: *Pus'erka*	Yushkin (1996)
Polar Ural Mountains—Voikaro-Syniiskii: *Levokechpelskoye*	Spiridonov (1998)
Siberia (Khahassia)—Sayan Mountains, Sokhatiny: *Borusskoye, Kashkarskoye*	Spiridonov (1998), V. Bukanov and N. Kuznetsov (pers. comm., 2000)
◆ North America	
Guatemala	
El Progresso—Motagua Valley: *Manzanal*	Harlow (1994), Gendron and Gendron-Dadou (1999)
Zacapa—Rio la Palmilla	G. Harlow (pers. comm., 1999)
JADE—Nephrite	
◆ Asia	
China	Wang (1996)
Guangxi	
Jiangxi	
Liaoning—Xiu Lan	
Qinghai–Gansu—Qilian Mountains	
Sichuan	
Taiwan	
Tibet	
Xinjiang Uygur—Altun Mountains; Kunlun Mountains: *Hotan, Yutian*; Tian Mountains	
Russia	
Polar Ural Mountains—Rai-Iz: *Nyrdvomenshor*	Yushkin (1996)
Siberia—Buryatia: *Khamarkhudinskoye*	V. Bukanov (pers. comm., 1999)
Siberia—Sayan Mountains, Vitim River: *Bortogolskoye, Buromskoye, Kurtushubinskoye, Ospinskoye, Paromskoye, Ulankhodinskoye*	Sekerina et al. (1996), Spiridonov (1998), V. Bukanov (pers. comm., 1999)
◆ Australia	
South Australia—Eyre Peninsula: *Cowell* (4)	Ward (1999a)
New Zealand	
South Island—Otago: *Lake Wakatipu*; Westland: *Arahura and Taramakau Rivers*	Keverne (1991)
◆ North America	
Canada	Sinkankas (1997)
British Columbia—**Cassiar Mountains**: *Polar Jade*	Ward (1999a,b)
British Columbia—Kutcho Creek, Ogden Mountain	Ward (1996b, 1999b)
United States	Sinkankas (1997)
Alaska—Afognak Island: *Danger Bay*; Baird Mountains: *Kobuk River*	Howard (1998)
California—Monterey: *Jade Cove*	Paradise (1985), Ward (1999b)
Wyoming—Lander: *Granite Mountains*	Ward (1999b)
OPAL	
◆ Africa	
Ethiopia	
Shewa—Menz Gishe: *Mezezo*	Downing (1996), Hoover et al. (1996), Johnson et al. (1996)
Madagascar	
Beraketa (50)	Henn et al. (1999b)
Tanzania	
Dodoma—Haneti Hills (22)	Keller (1992)
Kigoma—Kasulu (44)	Johnson and Koivula (1998b)
Kilimanjaro—Same (17)	A. Suleman (pers. comm., 1999)
Zambia	
Southern—Lake Kariba: *Maamba* (5)	Milisenda et al. (1994)
◆ Asia	
Indonesia	Lambert and Brown (1994)
Java—Jawa Burat: *Labak*	
Sulawesi—Selatan	
Sumatra—Bengkulu	

Gem material/locality	Reference
◆ Australia	
New South Wales—**Lightning Ridge** (1)	Gübelin (1990), Coenraads (1995)
New South Wales—**White Cliffs** (5)	Coenraads (1995)
Queensland—Carbine Creek (27), Jundah (24), Kynuna (26), Mayneside (25), Opalton (25), Quilpie (7), Toompine (23), Winton (8), Yowah (22)	Wise (1993)
Queensland—Eromanga (6)	Coenraads (1995)
South Australia—**Andamooka** (32), **Coober Pedy** (28)	Townsend (1995)
South Australia—Lambina (29)	Brown et al. (1993)
South Australia—**Mintabie** (28)	Brown (1992), Townsend (1992, 1995)
◆ North America	
Canada	
British Columbia—Vernon: Klinker	Koivula et al. (1993c), Yorke-Hardy (1994), Wight (1999a), Wilson (1999)
Mexico	
Querétaro—Querétaro	Spencer et al. (1992), Sinkankas (1997)
United States	Sinkankas (1997)
Idaho—Lemhi: *Spencer*	
Nevada—Humboldt: *Virgin Valley*	
Oregon—Morrow: *Opal Butte*	Holzhey (1997)
◆ South America	
Brazil	
Bahia	Koivula et al. (1994b)
Piauí—Pedro II (37)	Knigge and Milisenda (1997), Johnson and Koivula (1999c)
Rio Grande do Sul—Capão Grande (4)	Henn and Balzer (1995)
Peru	
Arequipa—Arequipa: *Acarí* (1)	Koivula and Kammerling (1991a,b), Brown (1996)

PERIDOT (Olivine)

◆ Africa	
Ethiopia	
Sidamo—Mega	Kammerling and Koivula (1995b)
Tanzania	
Arusha—Gelai: *Kingiti* (38)	Keller (1992)
◆ Asia	
China	Fashion for green... (1999)
Hebei—Zhangjiakou-Xuanhua	
Jilin—Changbaishan: *Baishishan*	More new finds... (1996)
Myanmar	
Mandalay—Mogok: *Bernardmyo* (1)	Hughes (1997)
Mandalay—Mogok: *Pyaung-Gaung* (1)	Kammerling et al. (1994b)
Pakistan	
Northwest Frontier—**Jalkot Valley, Kohistan**: *Parla Sapat* (7)	Koivula et al. (1994c,e), Milisenda et al. (1995), Frazier and Frazier (1997), Aboosally (1999)
Russia	
Siberia—Khatanga: *Kugda*	V. Bukanov (pers. comm., 1999)
Sri Lanka	
Southern—Monaragala: *Embilipitiya* (19); Ratnapura: *Kolonne* (32)	Milisenda and Henn (1999)
Vietnam	Kammerling and Koivula (1995a)
Annam Highlands—Gai Lai (Pleiku) (7)	
Lam Dong—Di Linh (6)	
◆ North America	
Canada	
British Columbia—Cherryville: *Lightning Peak*	Wilson (1999)
United States	
Arizona—Gila: *San Carlos*	Sinkankas (1997), Poeter (1999)

QUARTZ—Amethyst/Citrine/Ametrine

◆ Africa	
Kenya	
Eastern—Machakos: *Mbooni Hill* (1)	Keller (1992)
Madagascar	Henn et al. (1999b), Pezzotta (1999)
Antananarivo—Anjozorobe (42), Antsirabe (3), Betafo (2), Mahasolo (34), Soavinandriana (11), Tsiroanomandidy (33)	
Antsiranana—Ambilobe (12), Andapa (19)	
Fianarantsoa—Ambatofinandrahana (28); Ambositra (16); Farafangana: *Isamara* (35); Fianarantsoa: *Lacamisinten* (51); Vondrozo (20)	Aurisicchio et al. (1999)
Mahajanga—Boriziny (40), Kandreho (41), Tsaratanana (6)	
Toamasina—Andilamena (37), Mananara (39), Moramanga (38), Vatomandry (36)	
Mozambique	
Nampula—Alto Ligonha (1)	Malango and Taupitz (1996)
Namibia	
Grootfontein—Platveld Siding: *Dan, Okaruhuiput, Platfeld* (9)	Schneider and Seeger (1992), Koivula et al. (1994a)
Swakopmund—Uis: *Brandberg* (1)	Henn and Lieber (1993)
Tanzania	
Arusha—Lelatema (3), Tiriti (31)	Keller (1992)
Arusha—Mbulu (40)	A. Suleman (pers. comm., 1999)
Dodoma—Dodoma: *Mdindo* (4); Kilosa (6)	Keller (1992)
Dodoma—Mpwapwa (5)	Dirlam et al. (1992), Keller (1992)
Morogoro—Mvuha (30)	Dirlam et al. (1992)
Tanga—Handeni: *Negeru, Tamota* (7)	Keller (1992), Suleman et al. (1994)
Zambia	Mambwe and Sikatali (1994)
Central—Mumbwa (12)	
Eastern—Lundazi (2)	
Southern—Kalomo: *Mapatizya, Mwakambiko* (1); Siavonga (11)	
◆ Asia	
Afghanistan	
Kapisa—Del Parian (1)	Bowersox and Chamberlin (1995)
Cambodia	
Ratanakiri—Virochey: *Bo Kham, Voeune Sai, Xempang* (2)	Ngu and Ngoc (1986)
India	
Andhra Pradesh—Warangal (43)	S. Fernandes (pers. comm., 1999)
Jammu and Kashmir—Himachal Pradesh (65)	
Madhya Pradesh—Betul: *Bakka,* Ratera (52); Jabalpur: *Barela* (66)	S. Fernandes (pers. comm., 1999)
Madhya Pradesh—Deobhog: *Harrakothi* (19)	Jha et al. (1993)
Orissa—Balangir (10)	Choudhuri and Gurachary (1993)
Kazakhastan	
Qaraghandy—Vishnevka	Spiridonov (1998)
Myanmar	
Karen—Hlaingbwe River Valley (14)	U Hlaing (pers. comm., 1999)
Mandalay—Mogok: *Sakangyi* (1)	Kammerling et al. (1994b)
Shan—Makmai: *Wan Salaung* (28)	U Hlaing (pers. comm., 1999)
Russia	
Far East—Bikin: *Bikinskoye*	V. Bukanov (pers. comm., 1999)
Far East—Magadan: *Kedon River*	Smith and Smith (1995)
Kola Peninsula—Tersky Bereg: *Cape Korable*	V. Bukanov (pers. comm., 1999)
Lake Baikal—Ust'-Ilimsk: *Kroshunovskoye*	Smith and Smith (1995)
Middle Ural Mountains—Asbest: *Vatikha*	Evseev (1993b), Smith and Smith (1995), Emlin (1996), Spiridonov (1998)
Polar Ural Mountains—Komi: *Khasavarka*	Evseev (1993b), Spiridonov (1998)
Yakutia (Sakha)—Aldan: *Obman*	V. Bukanov (pers. comm., 1999)

Gem material/locality	Reference
Sri Lanka	Dissanayake and Rupasinghe (1993), Milisenda and Henn (1999)
Central—Anuradhapura: *Kekirawa* (28); Kandy: *Galaha* (26); Kegalla: *Avissawella* (9); Kurunegala: *Kurunegala* (21); Matale: *Rattota* (27); Nuwara Eliya: *Nuwara Eliya* (22)	
Southern—Monaragala: *Embilipitiya* (19); Ratnapura: *Balangoda* (2), *Eheliyagoda* (25), *Rakwana* (3), *Ratnapura* (1)	
Ukraine	
Volyns'ka—Vladimir-Volynsky	Evseev (1994b)
Zhytomyr—Zhytomyr: *Volodarsk-Volnskiy*	Smith and Smith (1995)
◆ North America	
Canada	
British Columbia—Slocan Valley: *Nelson*	Wilson (1999)
Ontario—Thunder Bay: *Keetch, Ontario Gem, Panorama*	Sinkankas (1997), B. Wilson (pers. comm., 1999)
United States	
Arizona—Maricopa: *Four Peaks*	Lurie (1999)
Maine—Oxford	Sinkankas (1997)
Maine—Stow	Koivula et al. (1993d)
New Hampshire—Carroll	Sinkankas (1997)
North Carolina—Lincoln	Sinkankas (1997)
◆ South America	
Bolivia	
Santa Cruz—Rincón del Tigre: *Anahí, Yuruty* (1)	Collyer et al. (1994), Vasconcelos et al. (1994), Marcusson (1996), Krzemnicki (2000)
Brazil	
Bahia—Brejinho (40); Cabeluda (23); Jacobina (2)	R. Batista and D. Epstein (pers. comm., 2000), Couto (2000)
Minas Gerais—Buenópolis (26)	R. Batista and D. Epstein (pers. comm., 2000)
Minas Gerais—Campo Belo (9)	Cassedanne (1995)
Pará—**Marabá**: *Alto Bonito* (11); **Pau d'Arco**: *Villa Esperança* (41)	Cassini et al. (1999)
Rio Grande do Sul—Ametista do Sul	Priester (1999)
Rio Grande do Sul—**Santa Maria**: *Planalto* (12)	Balzer (1999)
Rondônia—Porto Velho (7)	R. Batista and D. Epstein (pers. comm., 2000)
Roraima—São Luis de Anawa	R. Batista and D. Epstein (pers. comm., 2000)
Uruguay	
Artigas—Artigas (1)	Sosso and Roman (1992), Currier (1997)

QUARTZ—Rose

◆ Africa	
Madagascar	Henn et al. (1999b)
Antananarivo—Faratsiho (44), Sahatany Valley (3)	Pezzotta (1999)
Antananarivo—Tsiroanomandidy (33)	
Fianarantsoa—Ambositra (16)	Pezzotta (1999)
Toamasina—Ambatondrazaka (22), Moramanga (38)	
Toamasina—Andilamena (37)	
Mozambique	
Nampula—Alto Ligonha (1)	Malango and Taupitz (1996)
Namibia	
Swakopmund—Swakopmund: *Hoffnungsstrahl, Roselis* (7)	Schneider and Seeger (1992)
◆ Asia	
India	
Karnataka—Mysore (33)	S. Fernandes (pers. comm., 1999)
Madyha Pradesh—Deobhog (19)	Jha et al. (1993)
Tamil Nadu—Kangayam-Karur (54), Salem (17)	S. Fernandes (pers. comm., 1999)
◆ North America	
United States	
South Dakota—Black Hills	Sinkankas (1997)
◆ South America	
Brazil	
Minas Gerais—Sapucaia do Norte: *Sapucaia* (8)	B. Cook (pers. comm., 2000)

SPINEL

◆ Africa	
Madagascar	
Fianarantsoa—**Ilakaka–Sakaraha** (23)	Schmetzer (2000)
Toliara—Betroka (27)	Henn et al. (1999b), Pezzotta (1999)
Tanzania	
Morogoro—Magogoni (28), Mahenge (19), Matombo (27), Mvuha (30)	Dirlam et al. (1992), Keller (1992)
Ruvuma—Songea (42)	Dirlam et al. (1992)
Ruvuma—**Tunduru** (2)	Milisenda et al. (1997), Thomas (1997), Burford (1998)
Tanga—Handeni: *Kwachaga* (7)	Keller (1992)
Tanga—Umba Valley (21)	Dirlam et al. (1992), Keller (1992)
◆ Asia	
Afghanistan	Bowersox and Chamberlin (1995)
Badakhshan—Kuh-i-Lal (8)	
Kabul—Jegdalek (7)	Hughes (1994)
Cambodia	
Battamberg—Pailin (1)	
Myanmar	
Kachin—Mansi: *Panhka* (16)	U Hlaing (pers. comm., 1999)
Mandalay—Mogok: *Byant Gyi, Htayen Sho, Pyin Pit* (1)	Kammerling et al. (1994b), Hughes (1997), U Nanda (pers. comm., 1997)
Shan—Lai Hka: *Wan Ying* (8); Langhko: *Wan Hat* (10); Yawnghwe: *Mong Hsauk* (11)	U Hlaing (pers. comm., 1999)
Russia	
Siberia—Aldan: *Emeldzhak, Katalakh*	Evseev (1994a), Smith and Smith (1995)
Sri Lanka	Dissanayake and Rupasinghe (1993), Milisenda and Henn (1999)
Central—Badulla: *Haputale* (18), *Passara* (16); Kegalla: *Avissawella* (9); Nuwara Eliya: *Hatton* (15), *Kuruwitenna* (13), *Nawalapitiya* (29); Polonnaruwa: *Elahera, Kaluganga Valley* (8)	
Southern—Hambantota: *Ambalantota* (11); Kalutara: *Alutgama* (10), *Horana* (34); Matara: *Morawaka* (4); Monaragala: *Embilipitiya* (19), *Kataragama* (17), *Okkampitiya* (5); Ratnapura: *Balangoda* (2), *Eheliyagoda* (25), *Kalawana, Kiriella, Kuruwita, Nivitigala* (1), *Rakwana* (3)	
Tajikistan	
Turkistan—Khorugh: *Kukhilyal*	Kammerling et al. (1995e), Smith and Smith (1995)
Vietnam	
Yen Bai—Luc Yen (2)	Kane et al. (1991)

TOPAZ

◆ Africa	
Madagascar	Henn et al. (1999b)
Antananarivo—Ambatolampy (45)	A. Chikayama (pers. comm., 1999)
Antananarivo—Faratsiho (44)	
Fianarantsoa—Ambositra (16)	
Fianarantsoa—Ilakaka–Sakaraha (23)	Pezzotta (1999)
Mahajanga—Andriamena (46)	Pezzotta (1999)
Toamasina—Andilamena (37)	Pezzotta (1999)
Toliara—Mahabe (47)	
Namibia	
Karibib—Usakos: *Spitzkoppe* (2)	Menzies (1995), Cairncross et al. (1998)
Tanzania	
Arusha—Longido (9)	Dirlam et al. (1992)
Morogoro—Magogoni (28); Mvuha (30)	Dirlam et al. (1992)

Gem material/locality	Reference
Ruvuma—Tunduru: *Lumasulu, Muhuwesi River* (2)	H. Krupp (pers. comm., 1999)
Zimbabwe	
Mashonaland North—Mwami–Karoi (2)	Shmakin and Wedepohl (1999)
◆ Asia	
China	More new finds... (1996)
Guangdong	
Guangxi	
Xinjiang	
Yunnan—Gaoligongshan	
India	
Kerala—Trivandrum (9)	Menon et al. (1994), Rajesh-Chandran et al. (1996)
Orissa—Balangir (10)	Choudhuri and Guarchary (1993)
Orissa—Sambalpur: *Baghdapa* (5); Subarnapur: *Sonepur* (10)	S. Fernandes (pers. comm., 1999)
Kazakhstan	
Karagandin—Karaganda: *Akchatau*	Smith and Smith (1995)
Myanmar	
Mandalay—Mogok: *Sakangyi* (1)	Hughes (1997)
Pakistan	Blauwet et al. (1997)
Northern Areas—Baltistan: *Gone, Nyet Bruk* (3); Gilgit: *Buleche, Shengus* (2)	Menzies (1995)
Northwest Frontier—Katlang: *Ghundao Hill* (6)	Aboosally (1999)
Russia	
Middle Ural Mountains—Asbest: *Mursinka*	Evseev (1994a), Menzies (1995), Smith and Smith (1995), Kolesar (1997), Spiridonov (1998)
Southern Ural Mountains—Yushno-Uralsk: *Kochkarskoye*	V. Bukanov (pers. comm., 1999)
Transbaikalia—Krasna Chikoi: *Malkhan*	Evseev (1994a)
Sri Lanka	Dissanayake and Rupasinghe (1993), Milisenda and Henn (1999)
Central—Badulla: *Haputale* (18), *Passara* (16); Kurunegala: *Kurunegala* (21); Matale: *Matale* (7), *Rattota* (27); Nuwara Eliya: *Hatton* (15), *Nawalapitiya* (29); Polonnaruwa: *Elahera* (8)	
Southern—Kalutara: *Horana* (34); Ratnapura: *Balangoda* (2), *Ratnapura* (1)	
Tajikistan	
Turkistan—Pamir Mountains: *Rangkul, near Murgab*	Skrigitil (1996), Spiridonov (1998)
Ukraine	
Volyns'ka—Vladimir-Volynskiy	Menzies (1995), Spiridonov (1998)
Zhytomyr—Zhytomyr: *Volodarsk-Volynskiy*	Evseev (1994b), Smith and Smith (1995)
◆ Australia	
New South Wales—New England Range (10)	Webb and Sutherland (1998)
Queensland—Mount Surprise (20)	F. L. Sutherland (pers. comm., 1999)
◆ North America	
Canada	
British Columbia—Atlin, Mount Foster	Wilson (1999)
United States	
California—Ramona: *Little Three*	Foord et al. (1989)
New Hampshire—Carroll, Coos	Sinkankas (1997)
◆ South America	
Brazil	
Espírito Santo—Santa Teresa (16)	Cassedanne and Alves (1994), Menzies (1995)
Minas Gerais—Caraí: *Mucaia* (22); Itaipé: *Lavra do Aziz* (22); Pavão: *Ariranha* (22)	Cassedanne and Alves (1994)
Minas Gerais—**Ouro Prêto**: *Boa Vista, Capão, Dom Bosco, Vermelhão* (38)	Menzies (1995), Sauer et al. (1996)

TOURMALINE

◆ Africa	
Kenya	Keller (1992)
Coast—Kwale (12), Mgama-Mindi (21)	
Coast—Voi: *John Saul, Kisoli, Yellow* (13)	Simonet (2000)
Rift Valley—Magadi (14); Narok: *Osarara* (15)	
Madagascar	Henn et al. (1999b)
Antananarivo—Betafo: *Anjanabonoina* (2)	Pezzotta (1996, 1999)
Antananarivo—Antsirabe (3); Sahatany Valley: *Antandrokomby, Antanetyilapa, Ibity* (3)	Lefevre and Thomas (1997), Pezzotta (1999)
Fianarantsoa—Ambatofinandrahana (28); Ambositra: *Valzoro* (16); Farafangana: *Isamara* (35); Vondrozo (20)	Pezzotta (1999)
Fianarantsoa—Fianarantsoa (51)	
Fianarantsoa—Ilakaka–Sakaraha (23)	Hänni (1999), Pezzotta (1999)
Toamasina—Ambatondrazaka (22); Mananara (39)	
Mozambique	Malango and Taupitz (1996)
Nampula—Alto Ligonha: *Muiane, Naipa* (1)	Henn and Bank (1997)
Nampula—Nacala (5)	Correia Neves (1987)
Namibia	
Karibib—Usakos: *Neu Schwaben, Usakos* (8)	Schneider and Seeger (1992), Johnson and Koivula (1997f), Beard (1999)
Nigeria	
Oyo—**Ogbomosho**	Johnson and Koivula (1998g), Schmetzer (1999a)
Plateau—Keffi	Kanis and Harding (1990)
Tanzania	
Arusha—Babati (23), Merelani (15), Tiriti (31)	Dirlam et al. (1992)
Arusha—Landanai: *Titus-Tsakiris* (32)	Keller (1992), Suleman et al. (1994)
Arusha—Lelatema: *Lengasti* (3)	Dirlam et al. (1992), Keller (1992)
Dodoma—Chenene Mountains: *Hombolo* (33)	Keller (1992)
Dodoma—Mpwapwa (5)	Dirlam et al. (1992)
Kilimanjaro—Same (17)	Dirlam et al. (1992)
Morogoro—Magogoni (28); Matombo: *Linai* (27); Mvuha (30)	Dirlam et al. (1992)
Ruvuma—Tunduru: *Muhuwesi River* (2)	Milisenda et al. (1997), H. Krupp (pers. comm., 1999)
Tanga—Daluni (34); Handeni: *Kwachaga* (7); Ngomeni (35)	Keller (1992)

The Usakos mine in Namibia is the source of these tourmalines (6.94–11.29 ct). Courtesy of James Alger Co.; photo by Robert Weldon.

Gem material/locality	Reference
Tanga—Kwamsisi (36)	Dirlam et al. (1992)
Tanga—Umba Valley: *Gerevi Hills, Ngombezi* (21)	Dirlam et al. (1992), Keller (1992), Suleman et al. (1994)
Zambia	
Central—**Kabwe**: *Jagoda* (13)	Milisenda et al. (2000)
Eastern—Chipata (6)	Mambwe and Sikatali (1994)
Eastern—**Lundazi**: *Aries, Kalungabeba* (2)	Kamona (1994), Mambwe and Sikatali (1994), Johnson et al. (1997), Milisenda et al. (2000)
Eastern—Nyimba: *Hofmeyer* (7)	Kamona (1994), Milisenda et al. (2000)
◆ Asia	
Afghanistan	Bowersox and Chamberlin (1995)
Konar—Dhray-Pech, Kantiwa, Mualevi, Paprowk, Tsotsum, Vora Desh	
Laghman—Korghal, Mawi, Nilaw-Kolum (3)	
China	
Yunnan—Gaoligongshan	More new finds... (1996)
India	
Jammu and Kashmir—Himachal Pradesh (65)	Mehta (1997)
Karnataka—Mysore (33)	S. Fernandes (pers. comm., 1999)
Madhya Pradesh—Deobhog: *Latapara, Mukhagura, Sarnabahal, Sendmuna* (19)	Jha et al. (1993)
Orissa—Bagdihi (24); Sambalpur: *Sonepur* (5)	S. Fernandes (pers. comm., 1999)
Myanmar	Hughes (1997)
Kayah—Hsataw (27)	U Hlaing (pers. comm., 1999)
Mandalay—Mogok (1)	Kammerling et al. (1994b)
Sagaing—Madaya (13)	U Hlaing (pers. comm., 1999)
Shan—Makmai (28), Mong Hsu (3), Mong Pan (10)	U Hlaing (pers. comm., 1999)
Nepal	Niedermayer (1992)
Bheri—Surketh (6)	
Gandaki—Langtang (1), Naje (2)	
Gandaki—Marsyangdi Valley: *Manang* (2)	Koivula et al. (1994d)
Kosi—Sankhuwasabha: *Hyakule, Pahkuwa* (4)	Bassett (1987)
Mechi—Taplejung: *Ikhabu* (4)	
Rapti—Jajarkot (7)	
Pakistan	Blauwet et al. (1997)
Northern Areas—Gilgit: *Buleche, Shengus, Stak Nala* (2)	Laurs et al. (1998)
Northwest Frontier—Chitral (1); Neelum Valley: *Dongar Nar* (9)	
Russia	
Middle Ural Mountains—Asbest: *Lipovka*	Smith and Smith (1995), Emlin (1996), Zagorskii and Peretyazhko (1996), Spiridonov (1998)
Transbaikalia—Krasna Chikoi: *Malkhan, Menzinska*	Godovikov and Bulgak (1993), Evseev (1994a), Smith and Smith (1995), Spiridonov (1998)
Transbaikalia—Pervomayskoye: *Zavitinskoye*	V. Bukanov (pers. comm., 1999)
Sri Lanka	Dissanayake and Rupasinghe (1993), Milisenda and Henn (1999)
Central—Badulla: *Haputale* (18), *Passara* (16); Kegalla: *Avissawella* (9); Kurunegala: *Kurunegala* (21); Polonnaruwa: *Elahera, Kaluganga Valley* (8)	
Southern—Hambontota: *Ambalantota, Ridiyagama* (11); Kalutara: *Horana* (34); Matara: *Morawaka* (4); Monaragala: *Embilipitiya* (19), *Kochchipatana* (6), *Okkampitiya* (5); Ratnapura: *Balangoda* (2), *Eheliyagoda* (25), *Kiriella* (1), *Kuruwita* (1), *Rakwana* (3)	
Tajikistan	Zagorskii and Peretyazhko (1996)
Turkistan—Pamir Mountains: *Kukurt River, Rangkul*	Skrigitil (1996), Spiridonov (1998)
Turkistan—Horog: *Shakhdara River, Vezdara River*	
◆ North America	
United States	Sinkankas (1997)
California—Mesa Grande: *Himalaya*	Fisher et al. (1999)
California—Pala: *Stewart*	
Maine—Androscoggin: *Auburn*	Francis (1985)
Maine—Oxford: *Mount Apatite, Newry, Paris*	Francis (1985), Francis et al. (1993)
◆ South America	
Brazil	
Bahia—Brumado (30)	Cassedanne and Roditi (1996)
Bahia—Itamarati: *Lajedo* (1); Itambé: *Morro da Gloria* (24)	R. Wegner and O. Moura (pers. comm., 2000)
Ceará—Berilândia; Quixeramobim: *Condado* (39)	R. Wegner and O. Moura (pers. comm., 2000)
Minas Gerais—**Araçuaí–Jequitinhonha–Salinas–Virgem da Lapa:** *Baixa Grande, Barra de Salinas, Lavrinha, Manoel Mutuca, Morro Redondo, Ouro Fino, Pirineus, Salinas, Xanda* (18); **Malacacheta–Urupuca River–São José da Safira**: *Aricanga, Cruzeiro, Golconda, Santa Rosa* (19)	Cassedanne and Roditi (1996)
Minas Gerais—**Conselheiro Pena–Divino das Laranjeiras–Galiléia**: *Formiga, Itatiaia, Jonas, Pamaro, Sapo, Urucum* (8)	Cassedanne and Roditi (1996), Steger (1999)
Minas Gerais—Marambaia (22)	Proctor (1984)
Paraíba—Frei Martinho: *Alto Quixaba* (10)	Ferreira (1998)
Paraíba—Salgadinho: *São José da Batalha* (10)	Bank et al. (1990), Fritsch et al. (1990), Brandstätter and Niedermayr (1994), Cassedanne (1996), Laurs and Shigley (2000)
Rio Grande do Norte—Parelhas: *Alto da Cabeça, Bulandeira, Mulungu/Boqueirãozinho/Capoeira, Quintos* (10)	Karfunkel and Wegner (1996), Soares (1998), Laurs and Shigley (2000)
ZOISITE (Includes tanzanite)	
◆ Africa	
Tanzania	
Arusha—Mbuguni: *Merelani* (15)	Barot and Boehm (1992), Dirlam et al. (1992), Keller (1992), Suleman (1995), McDonald (1999), Wentzell (2000)
◆ Asia	
Pakistan	
Northern Areas—Skardu (3)	Koivula et al. (1992a)

This gem-quality tanzanite crystal from Merelani, Tanzania, measures 8.3 cm long. Courtesy of Pala International; photo by Jeff Scovil.

TABLE 2. Localities of the 1990s for less common gemstones.[a]

Gem material/locality	Reference
Apatite	
Brazil	R. Wegner and O. Moura (pers. comm., 2000)
Bahia—Itambé: *Bananeira* (24)	
Bahia—Jacobina: *Ibira* (2)	Koivula et al. (1993a)
Minas Gerais—Conselheiro Pena: *Aldeia* (8); Coroaci: *Golconda* (19)	
Paraíba—Pedra Lavrada: *Alto Feio* (10)	
India	S. Fernandes (pers. comm., 1999)
Karnataka—Mysore: *Katteri, Melkote* (33)	
Orissa—Kalahandi: *Banjipadar* (53)	
Tamil Nadu—Salem: *Kurumbapatti, Peryasoragai* (17)	
Kenya	
Eastern—Embu (2)	Barot et al. (1995)
Madagascar	
Antsiranana—Milanoa (13)	Kammerling et al. (1995a), Laurs (2000)
Toliara—Itrongay (43)	Pezzotta (1999)
Myanmar	
Mandalay—Mogok: *Kyaukpyatthat* (1)	Hughes (1997)
Russia	
Siberia—Lake Baikal: *Sludyanka*	Y. Shelementiev (pers. comm., 1999)
Sri Lanka	Dissanayake and Rupasinghe (1993), Milisenda and Henn (1999)
Central—Kegalla: Kegalla (9); Kurunegala: *Kurunegala* (21); Matale: *Matale* (7), *Nalanda* (23)	
Southern—Matara: *Akuressa* (4), *Deniyaya* (31); Ratnapura: *Balangoda* (2), *Eheliyagoda* (25), *Rakwana* (3), *Ratnapura* (1)	
Benitoite	
United States	
California—New Idria: *Benitoite Gem*	Frazier and Frazier (1990a,b), Laurs et al. (1997)
Charoite	
Russia	
Siberia—Olekminsk: *Murun (Chara River)*	Konev et al. (1993), Evdokimov (1995)
Chrome Diopside	
Russia	
Yakutia (Sakha)—Aldan: *Inagli*	Gadiyatov (1996), Johnson and Koivula (1996e), Spiridonov (1998)
Feldspar	Frazier and Frazier (1993a)
Australia	
Northern Territory—Harts Range (3)	Brown and Bracewell (1984)
Brazil	
Minas Gerais—Santa Maria de Itabira (3)	Cassedanne (1994), Karfunkel and Chaves (1994)
Canada	
Labrador	B. Wilson (pers. comm., 1999)
Finland	
Lymi—Lappenranta: *Ylämaa*	Frazier and Frazier (1993b), Johnson and Koivula (1997a)
India	Current mining report... (1998), S. Fernandes (pers. comm., 1999)
Bihar—Kodarma (68)	
Bihar—Patna (67)	Johnson and Koivula (1997c)
Kerala—Travancore (69)	
Orissa	
Tamil Nadu—Kangayam–Karur: *Karattupalayam, Kodanthur, Madiakattupudur, Odanalli* (54)	Kammerling et al. (1995b)
Tamil Nadu—Madurai (7); Salem (17)	
Madagascar	Pezzotta (1999)
Antananarivo—Betafo: *Ambohimanambola, Anjanabonoina* (2); Faratsiho (44)	
Fianarantsoa—Ambositra (16)	
Mahajanga—Kandreho (41)	
Toamasina—Ambatondrazaka (22)	
Toliara—Itrongay (43)	Weiss (1991)
Toliara—Mahabe (47)	
Myanmar	
Mandalay—Mogok: *Kyatpyin*, *Kyaukpyatthat* (1)	Hughes (1997)
Russia	
Ural Mountains—Kasil-Kishtim: *Potaniha*	Ostroumov (1991)
Sri Lanka	
Central—Badulla: *Haputale*, *Koslanda* (18)	
Southern—Galle: *Ambalangoda*, *Mitiyagoda* (24); Ratnapura: *Balangoda* (2), *Ratnapura* (1)	Harder (1992, 1994), Dissanayake and Rupasinghe (1993), Milisenda and Henn (1999)
Tanzania	A. Suleman (pers. comm., 1999)
Dodoma—Kondoa (41)	
Kilimanjaro—Same (17)	
Rukwa—Sumbawanga (10)	
United States	Johnston et al. (1991)
Oregon—Harney: *Ponderosa*	
Oregon—Lake: *Plush*	Henn and Bank (1992)
Iolite (Cordierite)	
Brazil	R. Wegner and O. Moura (pers. comm., 2000)
Paraíba—Nova Palmeira (10)	
Rio Grande do Norte—Parelhas (10)	
Canada	
British Columbia—Selkirk Mountains: *Slocan Valley*	Johnson and Koivula (1999a), Wight (1999b)
India	S. Fernandes (pers. comm., 1999)
Karnataka—Tumkur (35)	
Orissa—Boudh: *Kantamal, Manmunda* (13); Kalahandi: *Orhabahal*, *Urharanga* (53); Nawapada: *Burhapara* (63)	
Tamil Nadu—Kangayam–Karur: *Bommagoundanur, Uthampatty* (54); Madurai (7)	
Madagascar	
Antananarivo—Sahatany Valley: *Ibity* (3)	Lefevre and Thomas (1997)
Toliara—Toliara (49)	Pezzotta (1999)
Myanmar	
Mandalay—Mogok (1)	Hughes (1997)
Russia	
Siberia—Altai Mountains	Y. Shelementiev (pers. comm., 1999)
Sri Lanka	Dissanayake and Rupasinghe (1993), Milisenda and Henn (1999)
Central—Kegalla: *Avissawella* (9); Kurunegala: *Kurunegala* (21); Nuwara Eliya: *Hatton* (15); Polonnaruwa: *Elahera* (8)	
Southern—Monaragala: *Embilipitiya* (19); Ratnapura: *Ratnapura* (1)	
Lapis Lazuli	
Afghanistan	
Badakhshan—Kokcha Valley: *Sar-e-Sang* (6)	Bowersox and Chamberlin (1995)
Chile	
Andes Mountains—Ovalle: *Flor de Los Andes, San Marcelo, Seguridad* (1)	Ward (1996a), Coenraads and Canut de Bon (2000)
Myanmar	
Mandalay—Mogok: *Dattaw, Kabaing, Thapanbin* (1)	Kammerling et al. (1994b)
Russia	
Siberia—Lake Baikal: *Malobystrinkskoye*	Spiridonov (1998)
Tajikistan	
Turkistan—Pamir Mountains: *Lyadzhvardarinskoye*	Spiridonov (1998)

[a]*This chart includes key producing localities of the decade, with references to publications in the contemporary literature. The country name is followed by the province/state/region, then the district, and finally the mine/deposit/occurrence name (in italics). Numbers in parentheses refer to locations plotted on the regional maps. Some countries are not shown on these maps, and therefore do not have any numbers indicated.*

Gem material/locality	Reference
United States	
Colorado—Italian Mountain: *Blue Wrinkle*	Johnson and Koivula (1998c)
Maw Sit Sit	
Myanmar	
Kachin—Kansi: *Maw-sit* (15)	Colombo et al. (2000), Hughes et al. (2000)
Red Beryl	
United States	
Utah—Beaver: *Wah Wah Mountains*	Aurisicchio et al. (1990), Henn and Becker (1995)
Rhodochrosite	
Argentina	
Catamarca—Andalgalá: *Capillitas* (1)	Saadi and Grasso (1992), Cassedanne (1998)
United States	
Colorado—Park: *Sweet Home*	Knox and Lees (1997), Moore et al. (1998)
Rhodonite	
Canada	B. Wilson (pers. comm., 1999)
British Columbia	
Northwest Territories	
Russia	
Middle Ural Mountains—Ekaterinburg: *Kuaganovo*	Brusnitsyn and Serkov (1996)
Scapolite	
China	
Xinjiang—Kashi	More new finds... (1996)
Myanmar	
Mandalay—Mogok (1)	Couper (1991), Kammerling et al. (1994b), Hughes (1997)
Sri Lanka	Dissanayake and Rupasinghe (1993), Milisenda and Henn (1999)
Southern—Hambantota: *Ambalantota* (11); Kalutara: *Horana* (34); Matara: *Deniyaya* (31); Monaragala: *Embilipitiya* (19); Ratnapura: *Balangoda* (2), *Ratnapura* (1)	
Tajikistan	
Turkistan—Pamir Mountains: *Kurkurt, Rangkul*	Zolotarev (1993), Kammerling et al. (1995f), Skrigitil (1996)
Tanzania	
Dodoma—Dodoma (4)	Barot et al. (1995)
Sphene (Titanite)	
Australia	
Northern Territory—Harts Range (3)	McColl and Petersen (1990)
Canada	
Quebec—Chibougamau	Robinson and Wight (1997)
India	
Tamil Nadu—Karur: *Pattukaranur* (54)	S. Fernandes (pers. comm., 1999)
Madagascar	Pezzotta (1999)
Antsiranana—Daraina (48)	Johnson and Koivula (1998i), Laurs (2000)
Antsiranana—Milanoa (13)	
Myanmar	
Mandalay—Mogok (1)	Kammerling et al. (1994b), Hughes (1997)
Russia	
Ural Mountains—Perm: *Saranovskoe*	Hyrsl and Milisenda (1995), Kolesar (1997)
Sri Lanka	Dissanayake and Rupasinghe (1993), Milisenda and Henn (1999)
Central—Polonnaruwa: *Elahera* (8)	
Southern—Galle: *Galle* (12); Matara: *Akuressa*, *Morawaka* (4); Monaragala: *Kataragama* (17)	
Spodumene—Kunzite/Hiddenite	
Afghanistan	Bowersox and Chamberlin (1995)
Konar—Kantiwa, Vora Desh (2)	
Laghman—Mawi, Nilaw-Kolum (3)	
Brazil	Proctor (1984, 1985)
Minas Gerais—Galiléia: *Barra de Cuieté, Urucum* (8); Urupuca River: *Urupuca* (19)	
Minas Gerais—Conselheiro Pena: *Kunzita*, *Resplendor* (8)	
Madagascar	Henn et al. (1999b), Pezzotta (1999)
Antananarivo—Betafo (2), Ilakaka-Sakaraha (23)	
Antananarivo—Sahatany Valley: *Antsirabe* (3)	Lefevre and Thomas (1997)
Myanmar	
Mandalay—Mogok (1)	Hughes (1997)
Sri Lanka	
Southern—Monaragala: *Kataragama* (17)	Milisenda and Henn (1999)
United States	
California—Pala: *Stewart*	Sinkankas (1997)
Sugilite	
South Africa	
Cape—Hotazel: *Wessels* (7)	Shigley et al. (1987)
Turquoise	
China	
Hubei—Yungaisi	Liu (1999)
Iran	
Nischapur—Kuh-I-Binalud: *Maaden*	Gübelin (1999), Meister (1999)
Mexico	
Sonora—Cananea	Sinkankas (1997), Lieber (1999)
United States	Sinkankas (1997), Lieber (1999)
Arizona—Tucson: *Bisbee, Courtland, Lone Star, Morenci, Silver Bell, Sleeping Beauty, Turquoise Mountain*	
California—Mohave Desert: *Baker, Inyo Mountains*	
Colorado—Pueblo: *Cripple Creek, King's Manassa, Villa Brove*	
Nevada—Battle Mountain: *Austin, Cortez, Tenabo;* Tonopah: *Dusty Tim, Lone Mountain, Monte Cristo, Montezuma, Royal Blue*	
New Mexico—Alamagordo: *Jarilla*, *Lost Mine*; Cerillos: *Chaco Canyon, Mount Chalchihuitl, Turquoise Hill*; Silver City: *Burro Mountains, Little Hatchet Mountain*	
Zircon	
Australia	
New South Wales—New England Range (10)	F. L. Sutherland (pers. comm., 1999)
Northern Territory—Harts Range (3)	Faulkner and Shigley (1989)
Queensland—Anakie-Rubyvale (31)	F. L. Sutherland (pers. comm., 1999)
Cambodia	
Battamberg—Pailin (1)	Hughes (1997)
Madagascar	Pezzotta (1999)
Antananarivo—Antanifotsy (10)	
Fianarantsoa—Fianarantsoa (51)	
Fianarantsoa—Ilakaka-Sakaraha (23)	Hänni (1999), Henn et al. (1999b)
Toliara—Amboasary (14), Betroka (27)	
Myanmar	
Mandalay—Mogok (1)	Hlaing (1990a), Hughes (1997)
Nigeria	
Kaduna—Jemma	C. Arps (pers. comm., 1999)
Russia	Y. Shelementiev (pers. comm., 1999)
Far East—Primorskiy Krai	
Southern Ural Mountains—Chelyabinsk: *Ilmen Mountains* and *Vishnevie*	
Sri Lanka	Dissanayake and Rupasinghe (1993), Milisenda and Henn (1999)
Central—Badulla: *Haputale* (18), *Passara* (16); Kegalla: *Avissawella* (9); Nuwara Eliya: *Hatton* (15), *Nuwara Eliya* (22); Polonnaruwa: *Elahera* (8)	
Southern—Kalutara: *Alutgama* (10); Matara: *Akuressa*, *Morawaka* (4); Monaragala: *Embilipitiya* (19); Ratnapura: *Balangoda* (2), *Pelmadulla* (1), *Rakwana* (3), *Ratnapura* (1)	
Tanzania	
Kilimanjaro—Same (17)	A. Suleman (pers. comm., 1999)
Ruvuma—Tunduru: *Muhuwesi River* (2)	H. Krupp (pers. comm., 1999)

TABLE 3. Localities for cultured and natural pearls.[a]

Country / Area / Body of water	Mollusk	Predominant pearl color	Reference
Australia			
New South Wales	*Pinctada maxima* (White-lipped oyster, gold-lipped oyster)	White, "cream," "silver," "golden"	Muller (1999), A. Muller (pers. comm., 2000)
Northern Territory			Van Zuylen (1993), N. Paspaley (pers. comm., 2000)
Queensland			Doubilet (1991); A. Muller, N. Paspaley (pers. comm., 2000)
Western Australia			N. Paspaley (pers. comm., 2000)
Western Australia	*P. albina* (Arafura pearl oyster)	White	A. Muller (pers. comm., 2000)
Canada			
British Columbia	*Haliotis kamtschatkana* (Pinto abalone)	Green to blue, purple, red	Shirai (1994), Fankboner (1995), Wentzell (1998), Koethe and Bell (1999)
China—Freshwater			
Anhui, Hubei, Jiangxi	*Cristaria plicata* (River shell, wrinkle shell), *Hyriopsis cumingi* (Triangle shell)	White, "cream," yellow, orange, pink, purple, green	Pearl production in China…(1997), A. Muller (pers. comm., 2000), Tao (2000)
Guangdong	*H. cumingi*		Prices stable after years…(1998)
Guangxi	*H. cumingi, H. schlegi* (Biwa pearly mussel)		Peach (1999), A. Muller (pers. comm., 2000), Scarratt et al. (2000)
Jiangsu	*C. plicata, H. cumingi*		Sin (1993), Pearl production in China…(1997), Sheung (1999), A. Muller (pers. comm., 2000)
Zhejiang	*H. cumingi, H. schlegi*	White, "cream," yellow, orange, pink, purple, green	Sheung (1999), A. Muller (pers. comm., 2000), Tao (2000)
China—Saltwater			
Guangdong (including Hainan Island)	*P. Fucata* (Chinese Akoya oyster)	White, "cream," yellow, pink, blue	Chinese Akoya industry...(1999)
Guangxi			Akamatsu (1999), Chinese Akoya industry...(1999), Tao (2000)
Zhejiang	*P. maxima*	White, "cream"	Tao (2000)
Cook Islands[b]	*P. maculata* (Maculated pearl oyster)	Black, gray, blue to green	Buscher (1999)
	P. margaritifera (Black-lipped oyster)		Sims and Fassler (1994), Buscher (1999)
	P. maxima	White, "cream," "silver," "golden"	Sims and Fassler (1994)
French Polynesia			
Gambier	*P. margaritifera*, var. *cumingi* (Black-lipped oyster)	Black, gray, brown, blue to green, purple, yellowish green	R. Wan (pers. comm., 2000)
Society Islands			A. Muller (pers. comm., 2000)
Tuamotu Archipelago[b] (numerous islands)			Goebel and Dirlam (1989); R. Wan (pers. comm., 1999); S. Assael, M. Coeroli, A. Muller, C. Rosenthal (pers. comm., 2000)

The Chinese freshwater cultured pearls in this necklace and earrings measure approximately 8–9 mm long. Courtesy of Frank Mastoloni Sons; photo by Maha Tannous.

Australia became an important source of South Sea cultured pearls during the 1990s. The cultured pearls in these earrings (above) are from the north coast of Australia and measure 12 mm in diameter. Designed and manufactured by the Stirrups Collection/Paspaley Pearls.

Country / Area / Body of water	Mollusk	Predominant pearl color	Reference
Indonesia			
Maluku (several islands)	*P. maxima*	"Golden," white, "cream," "silver"	Johnson and Koivula (1997d), Muller (1999), A. Muller (pers. comm., 2000)
Sulawesi, Sumatra, Sumbawa			Muller (1999), A. Muller (pers. comm., 2000)
Japan—Freshwater			
Lake Biwa	*H. schlegeli*	White, "cream," pink, "silver," brown, orange, gray, blue	Shirai (1994)
Lake Kasumiga	*H. cumingi–H. schlegeli* hybrid	White, "cream," lavender, pink	C. Gregory (pers. comm., 2000)
Japan—Saltwater			Akamatsu (1999)
Ehime	*P. fucata martensii* (Akoya oyster)	White, "cream," yellow, gray, blue	A. Muller (pers. comm., 2000)
Mie (includes Ago Bay)			Shirai (1994), S. Akamatsu (pers. comm., 1999), A. Muller (pers. comm., 2000)
Nansei Shoto (several islands)	*P. margaritifera*	Black, gray, brown, blue to green, purple, yellowish green, white	A. Muller (pers. comm., 2000)
	P. maxima	White, "cream," "golden," "silver"	A. Muller (pers. comm., 2000)
Mexico			
Baja California[b]	*Pteria sterna* (Western winged pearl oyster)	Black, gray, "silver," blue to green	Hurwit (2000)
Baja California[b]	*P. mazatlanica* (Panamanian pearl oyster)	Black, gray, "silver," blue to green	Crowningshield (1991), Cariño and Monteforte (1995)
Guyamas			M. Goebel (pers. comm., 2000)
Myanmar	*P. maxima*	"Golden," white, "cream," "silver"	Tun (1999),Themelis (2000)
New Zealand			
Stewart Island	*Haliotis iris* (Paua, iris, or rainbow abalone)	Green to blue, purple, red	Wentzell (1998), McKenzie (1999)
North America			
Pacific Coast	*H. rufescens* (Red abalone), *H. fulgens* (Green abalone)	Green to blue, purple, red	Hurwit (1993, 1994), Fankboner (1995), Koethe and Bell (1999)
Philippines			Muller (1999)
Mindanao	*P. maxima*	"Golden," white, "cream"	Shirai (1994)
Palawan, Surgao Strait			D. Fiske (pers. comm., 1999)
Visayan Islands			Doumenge et al (1991)
South Africa	*Haliotis*	Green to blue, purple, red	Fankboner (1995)
United States—Freshwater			
Tennessee	*Megalonaias nervosa* (Washboard mussel	White, gray, "silver," with "rose" or blue overtone	Latendresse (1999)
United States—Saltwater			
Hawaii[b]	*P. margaritifera*	Black, gray, "silver," blue to green	Walther (1997)
Vietnam—Freshwater	*C. plicata*	White, "cream," pink	Bosshart et al. (1993)
Vietnam—Saltwater	*P. fucata*	White, "cream," yellow, pink,	Vietnam produces Akoya (1999)

[a]*A more detailed version of this table is available at the* Gems & Gemology *data depository on the Web site www.gia.edu/gandg.*
[b]*Indicates areas that reemerged in the 1990s after declining earlier in the 20th century due to overharvesting and/or environmental degradation.*

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1. The gemstone chapter of the Bureau of Mines *Minerals Yearbook*, published annually by the U.S. Department of the Interior.
2. *Mining Annual Review*, published by the Mining Journal, London.
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 every two years in the country where the conference is held.

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GEMSTONE ENHANCEMENT AND DETECTION IN THE 1990S

By Shane F. McClure and Christopher P. Smith

Gemstone enhancements and their disclosure became the most important gemological issue for the jewelry trade in the 1990s. Growing public awareness of treatments and the greater use of sophisticated technology to enhance the color and/or apparent clarity of gem materials brought to the forefront the need to maintain (or in some cases regain) the consumer confidence that is so vital to this industry. The treatments with the greatest impact were those that affected the gems that were commercially most important: heat and diffusion treatment of ruby and sapphire, "oiling" of emeralds, and fracture filling of diamonds. At the end of the decade, the decolorization of diamonds by high pressure and high temperature posed one of the greatest identification challenges ever faced by gemologists worldwide. Yet most other gem materials were also subjected to enhancements—ranging from traditional processes as with quench-crackled quartz to novel "impregnation" techniques such as the Zachery treatment of turquoise. This article discusses the treatments that were new or prominent during the '90s and suggests methods for their detection.

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At the time the previous retrospective article on gemstone enhancements was published by Kammerling et al. (1990a), enhancement disclosure was a concern of the jewelry industry, but it was still not a major international focal point. Since then, the issue of disclosure has caused a major upheaval throughout the trade, which has extended to all areas of the jewelry business, including diamonds (figure 1). In some cases, treatment disclosure—or the lack of it—has severely damaged the sale of certain gem materials by eroding the confidence of the consuming public in those gems. When consumers feel—rightly or wrongly—that a product is not being represented honestly, they are likely to stop buying that product.

One of the most drastic of these situations in the 1990s concerned emeralds. As a result of several events during the decade, consumers became aware that emeralds are routinely fracture filled, a fact that retailers typically were not disclosing. This new awareness coupled with the general lack of disclosure caused the public to feel that there must be something wrong with emeralds and they stopped buying them, creating a precipitous drop in the sale and value of these stones (see, e.g., Shigley et al., 2000a).

This is just one example of events throughout the '90s that made the subject of treatments—what they involve, how they can be identified, and how they should be disclosed—the most discussed gemological issue of the decade. Many questions about treatment disclosure are still being debated industry wide, and the answers are usually very complex. For this reason, this article will not seek to address the many ethical issues that haunt the trade. Rather, we will describe those gem treatments or enhancements that were first reported on or commonly performed during the last decade, and what can be done to detect them.

It is important to recognize that, for some of these enhancements, the detection methods needed have progressed far beyond the ability of most gemologists working in the trade, primarily because the instrumentation required

is often very sophisticated and expensive. We hope that this article will provide sufficient information to help a gemologist recognize when a stone may have been enhanced by such a method, so that he or she can determine whether it should be sent to a laboratory that has the necessary equipment.

THERMAL ENHANCEMENT

Thermal enhancement, or heat treatment, continues to be the most common type of treatment used for gems. Heat-treated stones are stable, and the result is permanent under normal conditions of wear and care. Heat treatment can be identified in some gem materials by routine gemological testing, and in others only by the use of advanced laboratory instrumentation and techniques. In still other gems, heat treatment is not identifiable by any currently known method. By the 1980s, virtually every gem species and variety known had been heated experimentally to determine if its appearance could be favorably altered. Many of the methods used both then and now are crude by modern standards, yet they can be very effective. During the 1990s, applications of, or improvements in, previously known technologies resulted in new commercial treatments. Perhaps the most important of these is the use of high pressure and high temperature (HPHT) to remove color in some brown diamonds and produce a yellow to yellowish green hue in others. These advances had a significant impact on the jewelry industry, some requiring the investment of enormous amounts of time and money to develop identification criteria.

Many gemstones—such as tanzanite, aquamarine, blue zircon, citrine, and the like—have been subjected to heat treatment routinely for several decades. Not only has the treatment of these stones become the rule rather than the exception, but in most cases there is no way to identify conclusively that the gem has been treated. Therefore, heat treatment of these stones will not be discussed here.

Ruby and Sapphire. As was the case in the preceding decade, the heat treatment of corundum remained a serious issue for the colored stone industry around the world. This treatment was applied to the vast majority of rubies and sapphires (figure 2) during the '90s to: (1) remove or generate color, (2) improve transparency by dissolving rutile inclusions, and/or (3) partially "heal" (i.e., close by the recrystallization of corundum) or fill surface-reaching fractures or fill surface cavities.

The primary concern that surrounded this enhancement was not the heat treatment itself, but the mostly amorphous substances that were left behind by the heating process in rubies (such features rarely have been encountered in sapphires). The disclosure that such substances were present in fractures and surface depressions caused a great deal of controversy in the industry, which contributed to the significant drop in price of heat-treated rubies in the latter half of the decade (see, e.g., Peretti et al., 1995; Shigley et al., 2000a). Many in the industry felt that this material was only a by-product of the heating process (Robinson, 1995), while others felt that it was put there intentionally (Emmett, 1999). Still others maintained that if fractures were being partially healed by this process, they were being healed with synthetic ruby (Chalain, 1995). Back-scattered electron images showed recrystallized corundum on the surface of one heat-treated ruby (Johnson and McClure, 2000). Although the material within the fractures was typically an artificial glass or similar substance, it was also found that natural inclusions could melt during the heat treatment and leave behind similar residual by-products (see, e.g., Emmett, 1999).

Figure 1. Gemstone enhancement and its disclosure became a critical issue in the 1990s, affecting not only rubies (here, 6.38 ct), emeralds (4.81 ct), and sapphires (6.70 ct), but colorless diamonds (5.05 ct) as well. Photo by Shane F. McClure.

Figure 2. The vast majority of rubies and sapphires are now routinely heat-treated. The color or clarity (or both) can be improved in many different types of corundum by this process. Photo by Shane F. McClure.

This debate was fueled primarily by the discovery of large quantities of ruby near the town of Mong Hsu in the upper Shan State of Myanmar (formerly Burma). Virtually all of this material had to be heated to improve its quality, either by removing the blue "cores" that typically occur down the center of the crystals or by filling or partially healing the many fractures (see, e.g., Peretti et al., 1995). The fluxes used during the heat-treatment process melt, flow into surface-reaching fractures and cavities, and subsequently re-solidify on cooling as an amorphous, vitreous solid (i.e., a glass). Because the fluxes can dissolve solid material in the fractures or even part of the corundum itself, the treatment process also may result in the formation of polycrystalline and/or single-crystal material in the fissure (see, e.g., Emmett, 1999). Currently, researchers and other gemologists are investigating the nature of the materials left behind after the heating process in Mong Hsu ruby. It is important to note, however, that heat-treated rubies from any locality (including Mogok) could contain these materials. In fact, the filling of surface-reaching pits, cavities, and fractures with "glassy" solids was first identified in ruby from Mogok and various deposits in Thailand during the early 1980s (Kane, 1984).

As the decade began, glassy materials were seen less frequently at the surface of heat-treated rubies, where they appeared as areas of lower surface luster in fractures and cavities. Recognizing that this was the evidence many laboratories used to detect such fillings, heat treaters and others in the trade began to routinely immerse the rubies in hydrofluoric acid to remove the surface material (figure 3). Consequently, gemologists had to focus more on the material that was still present in the fractures within the interior of the stone, which is much more difficult (if not impossible) to remove with acids. Note that the amount of residual glassy material left in partially healed or filled fractures is typically minuscule.

At the beginning of this decade, gemological laboratories had vastly different policies (see below)

concerning the nomenclature used to disclose these substances, which included "glass," "glassy," "glass-like," or "a solid foreign substance." In 1995, the Asian Institute of Gemmological Sciences in Bangkok became the first laboratory to introduce a system to denote the amount of this material that was present in a particular ruby. At the same time, they introduced the term *residue* to denote this substance (Johnson, 1996a). Their system described the presence of residue as *minor*, *moderate*, or *significant*. Most internationally recognized laboratories have since adopted similar terminology.

In fact, during this period, discussions took place in the trade and among laboratories specifically to address these nomenclature issues. Nevertheless, it will be very difficult for all international gemological laboratories to reach a consensus on how to present or describe this form of treatment, because different regions of the world have quite differing views on the subject. In the U.S., the trade demands more open disclosure because of legal concerns (see, e.g., Weldon, 1999a). On the opposite side of the spectrum are Southeast Asia and the Far East, where the trade typically wants little disclosure (see, e.g., Hughes and Galibert, 1998). Between these two is Europe, which traditionally follows the rules and regulations set out by CIBJO (International Confederation of Jewellery, Silverware, Diamonds, Pearls and Stones [see Editions 1991 and 1997]).

All of these factors served to confuse people in the trade and consumers alike. They not only contributed to a dramatic decrease in the price of heated rubies, but they also created greater demand for non-heated rubies and sapphires by the end of the decade.

Besides the continuation of the heating practices described in the previous retrospective article (Kammerling et al., 1990a), there were some significant new developments during the 1990s relating to the heat treatment of sapphire as well as ruby. First, equipment became increasingly more advanced. In addition to the more sophisticated control of temperature and atmosphere, some electric furnaces were also equipped for elevated pressure (Karl Schmetzer, pers. comm., 2000). Such advanced techniques led to the successful heat treatment of blue sapphires from Mogok, which was previously not commonplace (Kenneth Siu, pers. comm., 1997).

Heat treatment alters many of the properties and internal characteristics of rubies and sapphires. For those laboratories that provide locality-of-origin determinations, such modifications—coupled with the greater number of corundum sources found during the decade—only added to the complexity of determining the geographic origin of a ruby or sapphire (see, e.g., Schwarz et al., 1996). However, a number of articles did address the techniques used and the effects of heat treatment on sapphires from localities such as Kashmir (Schwieger, 1990), Sri Lanka (Ediriweera and Perera, 1991; Pemadasa and Danapala, 1994), Montana (Emmett and Douthit, 1993), Australia (Themelis, 1995), and Mogok (Kyi et al., 1999).

Proving that a stone has *not* been heat treated is often no simple matter, and it may require a significant amount of experience. Little new information was published in the '90s concerning the identification of this treatment in corundum. The criteria of the '80s, most of which require the use of a microscope, still apply. These include spotty coloration, cottonball-like inclusions, broken or altered rutile silk, internal stress fractures around solid inclusions, altered mineral inclusions, and chalky bluish to greenish white fluorescence to short-wave ultraviolet radiation (see, e.g., Kammerling et al., 1990a). It has been suggested that enhancement can be effected in some rubies and sapphires by heating them at lower temperatures, which might not produce the evidence normally seen in heat-treated corundum (John Emmett, pers. comm., 2000). This would make identification of the treatment even more difficult.

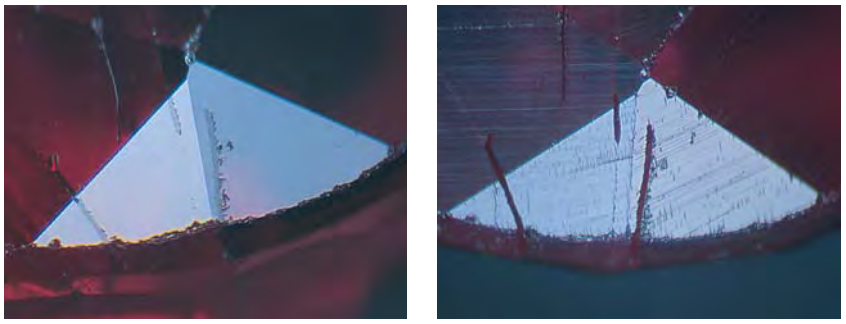


Figure 3. Rubies that have been fracture filled with a glassy substance can be detected by the lower luster in reflected light of the glassy material within the fractures (left). In the mid-'90s it became common for treaters or dealers to immerse these stones in hydrofluoric acid to remove this surface evidence (right). Photomicrographs by Shane F. McClure; magnified 40×.

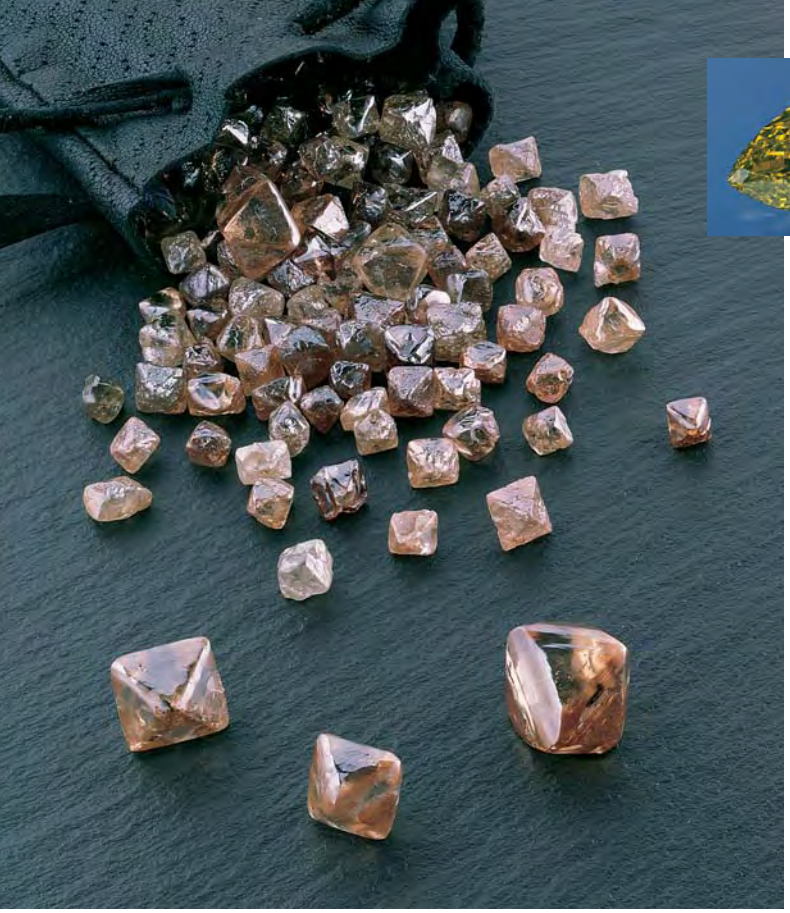


Figure 4. The color enhancement of diamond moved to the forefront late in the decade, when it was learned that new high pressure/high temperature techniques had been developed that could turn brown type IIa diamonds colorless and turn brown type Ia diamonds, similar to the rough diamonds shown here, yellow-green (inset, 4.45 ct). Photo by Shane F. McClure; inset photo by Maha Tannous.

Diamond. The close of the decade witnessed a dramatic new development in thermal enhancement. Beginning in approximately 1996, intense yellow to greenish yellow to yellowish green type Ia diamonds began to enter the international diamond market (see, e.g., Reinitz and Moses, 1997b). Soon thereafter it became known that the color in these diamonds, which were primarily thought to have originated in Russia, had been produced in type Ia diamonds by high pressure/high temperature annealing techniques (figure 4).

On March 1, 1999, Lazare Kaplan International subsidiary Pegasus Overseas Limited announced that they planned to market diamonds that the General Electric Company (GE) had enhanced by a proprietary new process (Rapnet, 1999). GE scientists soon confirmed that they were using HPHT annealing to *remove* color from type IIa brown diamonds (figure 5; see box A of Moses et al., 1999). This development sent a shockwave throughout the international diamond industry (see, e.g., Barnard, 1999; Weldon, 1999b,c). Gemological and research laboratories around the world soon began the task of developing a means to detect these HPHT-enhanced diamonds (see, e.g., Moses et al., 1999; Chalain et al., 1999, 2000). Currently, several characteristics have been identified that may indicate if a diamond has been exposed to HPHT conditions. Unfortunately, most are not within the scope of techniques available to the average gemologist, because they depend heavily on absorption and/or photoluminescence spectral features present at low temperatures (see, e.g., Fisher and Spits, 2000; Reinitz et al., 2000b; Smith et al., 2000). Nevertheless, the process may produce some indications that are visible with a microscope. These relate primarily to damage caused by the extreme conditions of the treatment, such as etched or frosted naturals, or fractures that are partially frosted or graphitized where they come to the surface (figure 6). It must be emphasized that these are indications only, and they may be difficult to recognize for all but the most experienced observers.

By the end of the decade, a number of different groups in various countries were modifying the color of diamonds by exposure to HPHT conditions (see, e.g., Moses and Reinitz, 1999). The majority of these stones are the yellow to yellowish green type Ia diamonds, but more than 2,000 "decolorized" type IIa diamonds had been seen in the GIA Gem

Figure 5. This 0.84 ct piece of type IIa diamond rough was HPHT annealed by General Electric for GIA researchers. The original dark (approximately equivalent to Fancy) brown material (left) was changed to approximately "G" color (right) after being subjected to the process. Photos by Elizabeth Schrader.

Trade Laboratory by the end of 2000. Most recently, HPHT-processed pink type IIa diamonds and even a limited number of blue type IIb diamonds have appeared (Hall and Moses, 2000).

Tourmaline. The 1989 discovery of elbaite tourmaline in Brazil's Paraíba State revealed colors that had never before been seen in this gem species. It was soon determined that exposure to high temperatures could produce a vivid blue or green hue in some crystals from this deposit; the "emerald" green was not known to occur naturally (Fritsch et al., 1990). The heat treatment of these tourmalines (commonly referred to as "Paraíba" tourmaline) continued throughout the 1990s, even though finds of this material declined as the decade progressed. Other types of tourmaline from various countries also continued to be heat treated during the 1990s. However, as with the Paraíba material, such treatment cannot be identified in these tourmalines by standard gemological methods.

Topaz. Pink topaz continues to be produced by exposing brownish yellow to orange "Imperial" topaz from Brazil to elevated temperatures (figure 7). This color does occur naturally in topaz from a number of localities, including Brazil.

The most recent report on the mining and heat treatment of Imperial topaz was done by Sauer et al. (1996). This article described a possible new test for detecting heat treatment in topaz. The limited number of heated stones in this study showed a distinct change in short-wave UV fluorescence from a very weak to moderate chalky yellow-green in the untreated stones to a generally stronger yellowish or greenish white in the treated stones. As the authors noted, more research is needed to determine the reliability of this test.

Zoisite. Most people in the trade are now familiar with the fact that the color of the vast majority of tanzanite in the market is the result of the heat treatment of brown zoisite. In 1991, however, transparent green zoisite was discovered. Although the finds to date have been relatively small and sporadic at best, limited experimentation showed that only a small percentage of this material responded to heat treatment, changing from the original bluish green through brownish green to a greenish blue. Barot and Boehm (1992) suggested that green zoisite was not routinely being heated because of the rarity of this material.

Figure 6. This fracture in an HPHT-annealed yellow-green diamond has partially graphitized, which is an indication that the stone has been subjected to high pressure/high temperature conditions. However, the presence of graphitization should not be construed as proof of treatment. Photomicrograph by Shane F. McClure; magnified 31×.

As is the case with many other materials, at this time heat treatment in zoisite is not detectable in most cases.

Amber. Several reports in the '90s described a kind of surface-enhanced amber, where a dark brown layer of color is generated at a shallow depth by exposing the amber to controlled heating, up to

Figure 7. Heat treatment of brownish yellow to orange Imperial topaz from Brazil changes the color of the material to pink, such as the piece shown here on the lower left. The larger crystal weighs 115.0 ct. Photo by Maha Tannous.

Figure 8. This heat-treated amber bead has been ground down on opposite sides to show that the color imparted by the treatment is confined to a thin surface layer. The dark brown hue fades on prolonged exposure to light. Photomicrograph by Shane F. McClure; magnified 10×.

approximately 220°C (Crowningshield, 1993; Hutchins and Brown, 1996; Safar and Sturman, 1998). In many cases, the interior of this material is left almost colorless (figure 8). With prolonged exposure to light, however, the dark surface layer proved to be unstable, fading to a much lighter tone.

This treated amber can be recognized by a dull, chalky green fluorescence to long-wave UV, rather than the stronger orange fluorescence of untreated material, as well as by the presence of numerous tiny gas bubbles in swirling clouds just below the surface of the stone.

Other Gem Materials. It seems that people in our trade have a fascination with exposing gemstones to heat, just to see what happens. Some examples of this reported during the past decade include changing the color of blue benitoite to orange (Laurs et al., 1997), yellow chalcedony to carnelian (Brown et al., 1991), and rhodolite garnet to a more brownish color with a metallic oxide coating (Johnson and Koivula, 1997a).

DIFFUSION TREATMENT

Corundum. At the beginning of this decade, the trade witnessed a dramatic resurgence in diffusion-treated blue sapphire (e.g., Kane et al., 1990; Hargett, 1991). This resurgence was attributed to a new technique that allowed for a much deeper penetration of the diffused color, which came to be known as "deep diffusion" in the trade. For a time, these stones seemed to have a certain degree of trade acceptance, and large diffusion-treated sapphires—some exceeding 20 ct—were produced (e.g., Koivula and Kammerling, 1991b). By the mid-'90s, however, interest in this material had declined dramatically (Koivula et al., 1994). We believe that, for the most part, these stones were being marketed and disclosed properly, although there were several incidents of diffusion-treated sapphires being "salted" in parcels of natural-color blue sapphires (Brown and Beattie, 1991; Koivula et al., 1992d).

Identification of this material is best accomplished by immersing it in methylene iodide. Diffusion treatment in sapphires is characterized by color concentrations along facet junctions, patchy surface coloration, and higher relief in immersion when compared to an untreated stone (Kane et al., 1990). It was recently reported that some diffused sapphires do not show the characteristic concentrations along facet junctions, which are caused by the stones being repolished after treatment (Emmett, 1999). This was attributed to the possible use of a molten titanium-bearing flux instead of a powder, which could eliminate the need for repolishing. Such stones can still be identified by the "bleeding" of color into surface-reaching features such as "fingerprints," fractures, and cavities, or by their characteristic higher relief in immersion.

The most significant new development in diffusion treatment during the decade was the introduction of red diffusion-treated sapphire (often called diffusion-treated ruby), as described by McClure et al. (1993). This type of diffusion treatment never seemed to gain wide usage, probably because of the difficulties inherent in diffusing chromium into the surface of corundum. These difficulties result in a very shallow surface layer of color, as well as in some unwanted colors such as purple and orange (Koivula and Kammerling, 1991f,g; McClure et al., 1993; Hurwit, 1998). One of the authors (CPS) was informed that when this material first came out, several prominent ruby dealers in Bangkok paid very high prices for diffusion-treated "rubies" that were represented as heated only.

Diffusion-treated "rubies" can be identified readily by their patchy or uneven surface coloration, color concentrations along facet junctions, relatively high relief in immersion (figure 9), very high surface concentrations of chromium, very high refractive index, patchy bluish white to yellowish white short-wave UV fluorescence, and atypical dichroism (see, e.g., McClure et al., 1993).

Figure 9. Immersion in methylene iodide reveals the patchy surface coloration, color concentrations along facet junctions, and high relief (when compared to untreated stones) of these red diffusion-treated sapphires. Photo by Shane F. McClure.

Occasionally encountered were corundums that owed their asterism, as well as their coloration, to diffusion treatment (e.g., Crowningshield, 1991, 1995c; Johnson and Koivula, 1996c, 1997c). Even colorless synthetic corundum was diffusion treated (Koivula et al., 1994; Crowningshield, 1995b; Johnson and Koivula, 1998a).

Topaz. We first encountered what was being represented as "diffusion treated" topaz in 1997 (Johnson and Koivula, 1998d). However, it is still not clear if the cobalt-rich powders employed during the enhancement process actually diffuse into the lattice of the topaz. Nevertheless, the green-to-blue colors of this material (figure 10) are quite different from the orange, pink, or red hues we have seen in topaz colored by a surface coating (Johnson and Koivula, 1998d; Hodgkinson, 1998; Underwood and Hughes, 1999). The "diffusion treated" material is easily identified by its spotty surface coloration. The colored layer is as hard as topaz and is so thin that no depth was visible in a prepared cross-section, even at 210× magnification (Johnson and Koivula, 1998d).

IRRADIATION

In the 1980s, experimental and commercial irradiation played a significant role in the arena of gemstone treatment (Kammerling et al., 1990a). During the following decade, however, the role of irradiation diminished considerably when compared to other forms of enhancement. In the 1990s, very few new types of artificially irradiated gems appeared on the market, although there were a number of changes or improvements made to the methods used with some already well-known irradiated gems, such as blue topaz (Fournier, 1988; Skold et al., 1995). During this decade, gemologists and gem laboratories continued to see irradiated gem materials, but very little of what they saw was actually new.

Figure 10. "Diffusion treated" green-to-blue topaz (here, 4.50–5.86 ct) was first seen in the late 1990s. While it has not yet been proved adequately that the color is actually diffused into these stones, the extremely shallow color layer is as hard as topaz. Photo by Maha Tannous.

Figure 11. The red color in this 0.55 ct synthetic diamond was produced by irradiation and subsequent annealing. Photo by Robert Weldon.

Likewise, there was little progress in detection methods. For many gems, no test or series of tests, destructive or nondestructive, is currently available to establish whether they have been subjected to irradiation. Unless the technique used produces a visually distinctive pattern in a treated stone, such as the "umbrella effect" seen around the culet of a cyclotron-treated diamond, the use of irradiation to improve a gemstone's color still can be difficult or impossible to detect gemologically. For example, although treaters have used irradiation to produce intense pink-to-red colors in near-colorless to light pink tourmaline for many years, this well-known form of color enhancement is still not detectable. This is also the case for blue topaz, as well as for many other gem materials that are routinely irradiated.

Yet another factor to consider in the detection of any suspected means of treatment, including irradiation, is economics. While it may be economically feasible and even imperative to attempt to detect irradiation-induced color enhancement in a fashioned green diamond, the same is usually not the case with respect to smoky quartz or blue topaz. The low value of the starting materials, and the limited potential gain in value of those materials after color enhancement, does not warrant a significant expenditure in laboratory time to attempt to detect the treatment.

Radioactivity is a word that stirs particularly strong emotions in the public at large. This is primarily due to a widespread lack of understanding concerning the various forms of irradiation and their short-lived or long-lasting effects. If there is anything that generates press quickly, it's the detection of residual radioactivity in an irradiated gem and the potential threat to health it suggests. Diamond, ruby, chrysoberyl, spodumene, and topaz are a few of the gem materials that have shown residual radioactivity after color enhancement by irradiation.

Diamond. Irradiation to improve or induce color in diamond is generally performed on faceted stones, because usually the need for color improvement can be determined accurately only after a stone has been cut. However, rough diamonds are also occasionally irradiated. A 13.12 ct treated-color yellow rough diamond was reported late in the decade (Reinitz, 1999). Treatment of rough is a highly questionable practice, since such material is often misrepresented. The fact that some treatment methods produce only a shallow layer of color that can be removed easily on faceting strongly suggests that the treatment is only done to deceive.

Unfortunately, most radiation-induced color patterns in faceted diamonds, such as those produced by electron bombardment, are subtle and difficult to detect. Careful inspection with a gemological microscope, however, may show color zoning that is directly related to the facet shape of the diamond (Fritsch and Shigley, 1989). Artificially irradiated diamonds that show subtle but diagnostic forms of color zoning in blue to green (Hargett, 1990; Hurwit, 1993; Moses and Gelb, 1998) and reddish purple (Reinitz and Moses, 1998) were encountered regularly throughout the 1990s. Diffuse transmitted light is useful in the detection of treatment in these stones if the light can be directed through the diamond. To facilitate light transmission, total or partial immersion of the diamond in methylene iodide is often helpful.

A number of treated pink to purplish pink diamonds encountered in the '90s (Crowningshield and Reinitz, 1995; King et al., 1996) did not show color zoning that could be related to irradiation. In such cases, both the diamond's reaction to UV radiation (bright, chalky orange to both long- and short-wave) and its spectrum (sharp absorption lines at 595, 617, and 658 nm) are distinctive of treatment. Although irradiation-produced pink in diamonds was previously rare and usually accidental

(Kammerling et al., 1990a), significant quantities of laboratory-irradiated pink diamonds (typically melee-size) appeared on the market in the latter half of the decade.

Also encountered in the 1990s were diamonds irradiated to such a dark green that they appeared essentially opaque and black in all jewelry applications. These diamonds are identified by the fact that they are dark green instead of the dark gray of natural black diamonds, which is caused by inclusions (Kammerling et al., 1990b). Some of these "black" stones are treated in a nuclear reactor, which can result in residual radioactivity. One such treated diamond examined in the GIA laboratory was sufficiently radioactive to render it unlawful to sell for almost 37 years (Reinitz and Ashbaugh, 1992). Another report on "black" irradiated diamonds stated that the residual radioactivity was related to metallic polishing residues in surface-reaching cracks that became radioactive when the stones were irradiated. Prolonged boiling in acid removed the radioactive residues and rendered these treated diamonds safe (Koivula et al., 1992h).

Irradiation and annealing also can change synthetic diamonds from yellow and brownish yellow to red (figure 11—Moses et al., 1993; Kammerling and McClure, 1995c). These treated synthetic stones do not present significant identification problems because they have distinctive spectra (the same as for treated pink diamonds mentioned above) and all the internal characteristics expected of synthetic diamonds. The short-wave UV fluorescence is particularly distinctive, as these treated-color red synthetic diamonds almost always show a bright green "cross" in the middle of the table with orange throughout the rest of the stone (figure 12; Moses et al., 1993).

Ruby. Radioactive rubies were new to the gem trade in the 1990s. These stones first appeared on the market in Jakarta, Indonesia, and were reported in the trade press in mid-1998 ("Indonesia: Irradiated ruby…," 1998). Two of these stones were examined by Ken Scarratt at the AGTA Gemological Testing Center, who subsequently loaned them to GIA for photography and further study (Johnson and Koivula, 1998c). The slightly brownish red stones closely resembled rubies from East Africa. Both showed clear evidence of heat treatment and were partially coated with a black crust of unknown origin that appeared dark brown along thin edges.

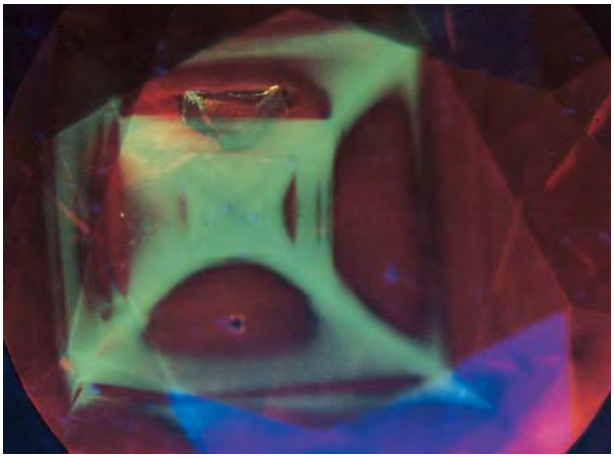


Figure 12. A characteristic property of irradiated red synthetic diamonds is their short-wave UV fluorescence, which typically shows a strong green "cross" in the center of the stone surrounded by weak orange. Photomicrograph by John I. Koivula; magnified 15×.

The isotopes responsible for the residual radioactivity in these stones were not determined, so we do not know just how long the stones would remain radioactive. To date, no information has become available as to the precise source of these rubies and their original starting color.

These radioactive rubies cannot be recognized by any standard gemological means. The only indications are their brownish color and the black crust. However, these indications are unreliable. Fortunately, we know of no further reports of these stones in the marketplace.

Chrysoberyl. Yet another form of radioactive gem material appeared in the 1990s. Hundreds of carats of cat's-eye chrysoberyl of an unusual dark brown color were sold at gem markets around the world. These cat's-eyes showed a dangerous level of radioactivity—50 times greater than that which is legally acceptable in the United States—and were thought to have been treated in a nuclear facility in Indonesia (perhaps the same source as for the radioactive rubies described above). The original starting material is believed to have come from Orissa, India (Weldon, 1998b). All dark brown cat's-eye chrysoberyls are suspect until they are tested for radioactivity by a properly equipped gemological laboratory.

Figure 13. These two "Ocean Green" irradiated topazes (3.00 and 3.13 ct) were originally the same color, but after being taped to a south-facing window for one day, the stone on the left lost almost all of its green component. Photo by Maha Tannous.

Topaz. Large amounts of irradiated blue topaz continued to be seen in the international gem market. Irradiated green topaz with unstable color (figure 13) was reported (see, e.g., Koivula et al., 1992f; Ashbaugh and Shigley, 1993). It was marketed under the trade name Ocean Green Topaz. Because the color is produced by irradiation in a nuclear reactor, like other reactor-treated gems this green topaz has the potential to be radioactive. The color ranges from light to medium tones of yellowish and brownish green through a more saturated green to blue-green. On exposure to one day (or less) of sunlight, the green component fades, leaving a typical blue topaz color. The relative tone and saturation remain the same.

The original starting material is said to have come from Sri Lanka. Green topaz has been reported to occur in nature, but it is very rare. With this in mind, any green topaz should be suspected of some kind of treatment.

Quartz. Pale gray cat's-eye quartz was being irradiated to a dark brown to enhance the appearance of the chatoyancy by having the bright, reflective, inclusion-caused "eye" appear against a dark background (Koivula et al., 1993a). Also reported was the gamma irradiation (followed by heat treatment) of colorless quartz to produce colors ranging from green through yellow and orange to brown (Pinheiro et al., 1999). All of the colors were stable to light. No tests are presently available to detect the treatment in these stones.

Beryl. Maxixe beryl, the dark blue beryl that owes its color to natural or (usually) artificial irradiation, appeared again in the 1990s, in at least one instance as a substitute for tanzanite (Reinitz and Moses, 1997a). Another report reviewed its susceptibility to fading (in most cases, dark blue is an unstable color in beryl) and the gemological properties used to recognize this type of beryl (Wentzell and Reinitz, 1998).

DYEING

Although dyeing is one of the oldest treatments known, the 1990s witnessed a number of apparently new variations on beryl, corundum, jade, and opal, among other gem materials. Especially convincing were dyed quartz and quartzite imitations of gems such as amethyst and jadeite. At the same time, the proliferation of inexpensive cultured pearls brought with it a multitude of colors produced by dyes.

Beryl. In addition to the standard dyeing techniques used to enhance pale green beryls to an emerald color or colorless beryl to aquamarine (e.g., quench crackling, or drill holes coated with dye; Koivula et al., 1992b), the market saw the continued use of green oils and the introduction of green Opticon as fracture fillers (Koivula and Kammerling, 1991a). Using a combination of heat (to increase porosity and thus color penetration) and dye, Dominique Robert of Switzerland turned massive beryl with intergrown quartz into imitations of ornamental materials such as charoite and sugilite, as well as turquoise and coral (Koivula et al., 1992e). As is the case with most dyed stones, the treatment was readily identifiable by the presence of dye concentrations in the fractures.

Corundum. Although the red staining of quartz that has been heated and quenched ("crackled") to induce fissures dates back hundreds of years, for the first time gemologists identified corundum in which fractures had been induced and the pale sapphires then dyed a purplish red. These stones were recognized by the irregular color distribution and the presence of a yellow fluorescence confined to the stained fractures; they also lacked the red fluorescence and Cr lines in the spectroscope that are characteristic of ruby (Schmetzer et al., 1992). A similar process was also seen in dyed natural star corundum (Schmetzer and Schupp, 1994). Dyed red beads examined in the

GIA Gem Trade Laboratory responded to a simple acetone test; removal of the dye from one bead revealed that it originally was a pale green sapphire (Crowningshield and Reinitz, 1992).

Jadeite. Colored substances have been used to fill cavities in bleached and impregnated jadeite (Johnson and McClure, 1997b). These fillers are readily visible with a microscope.

Of particular concern was the identification of dye in a green jadeite bangle that did not show the typical dye band with the handheld spectroscope (Johnson et al., 1997). This piece first aroused suspicion when the expected absorption bands for chromium were not seen in the spectroscope. The bangle was of sufficient color that these bands should have been present if the color was natural, so the piece was examined very carefully with a microscope. Fortunately, in this case the dye was evident as color concentrations along grain boundaries (figure 14).

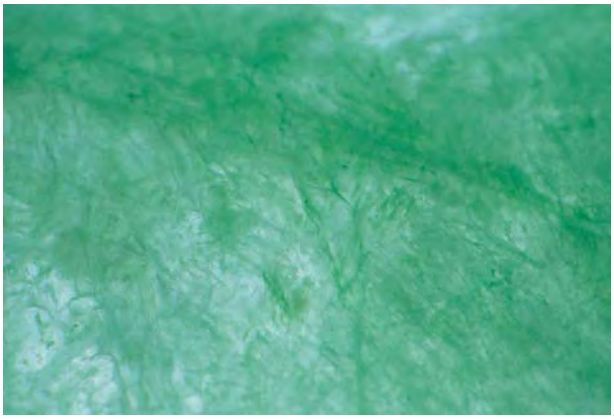


Figure 14. Careful microscopic examination revealed dye concentrations in this piece of jadeite, which did not show the dye spectrum typical of this type of material. Photomicrograph by Shane F. McClure; magnified 34×.

Opal. Because of its porosity, opal has long been subjected to enhancements such as the "sugar" treatment commonly used on Andamooka material to darken the background so the play-of-color is more prominent (see, e.g., Brown, 1991). During the 1990s, however, we also saw opal darkened by silver nitrate (similar to the treatment used to produce black in pearls). As with the sugar-treated material, the silver nitrate treatment is evidenced by the presence of dark irregular specks (Koivula et al., 1992i). In still another process, opal-cemented sandstone is soaked in an organic solution and then carbonized at temperatures over 500°C to produce an attractive carving material (Keeling and Townsend, 1996). Particularly interesting was the introduction of dark blue enhanced opal, produced by soaking a highly porous chalky white hydrophane opal in a mixture of potassium ferrocyanide and ferric sulfate (Koivula et al., 1992c). This material looks black to the unaided eye, but strong transmitted light reveals its unnatural dark blue body color.

Pearls. Numerous examples of black cultured saltwater pearls that had been dyed with a silver nitrate solution (figure 15) were seen during the '90s, including some mixed with natural black pearls in a fine necklace (DelRe, 1991). The treated pearls were first spotted by the lower contrast on the X-ray film between the shell bead and the nacre; their chalky green appearance to long-wave UV confirmed that they were dyed. Other indications of silver nitrate staining include damage to the nacre layers or, occasionally, a dimpled surface (Moses, 1994). Of particular concern toward the end of the decade was the prevalence of dyed "golden" South Sea cultured pearls. Unfortunately, the natural or treated origin of these pearls often cannot be determined ("Pearl treatments...," 1998). Whereas the colors of dyed saltwater pearls are usually fairly limited (black, brown, dark green, and "golden"), freshwater cultured pearls have been dyed in a wide array of hues, including "silver," "bronze," and bright "pistachio"

Figure 15. This cultured pearl was turned black with a metallic oxide, most likely by the use of a silver nitrate solution. Photo by Jennifer Vaccaro.

Figure 16. Quartzite dyed green to imitate jadeite, as illustrated by these 8 mm beads, was commonly seen in the 1990s. Photo by Maha Tannous.

green (Johnson and Koivula, 1999). In many cases these dyed pearls can be identified by their unnatural color alone, or by the presence of dye concentrations around drill holes or just under the surface of the pearls.

Quartz. For literally thousands of years, quartz has been quench-crackled and dyed to imitate more valuable gem materials such as ruby and emerald. During the last decade, we observed for the first time quartz beads that had been quench-crackled and dyed to imitate amethyst (Reinitz, 1997b). In at least one sample, green dye had been mixed with an epoxy resin such as Opticon before it was introduced into the quench-crackled stone (Koivula et al., 1992j).

Of particular interest were unusual dyed quartzites (a metamorphic rock composed primarily of quartz grains) in colors such as purple (to imitate sugilite; Reinitz and Johnson, 1998). One of the most convincing of such imitations was quartzite dyed to imitate jadeite, both lavender (Koivula and Kammerling, 1991c) and green (figure 16; Kammerling, 1995a). As with most dyed gems, though, dye concentrations in the fractures and between grains provided a strong indication of treatment.

CLARITY ENHANCEMENT

The previous retrospective article titled this section "Oiling/Fracture Filling." Since that time, it has become commonplace to refer to such treatments as clarity enhancement, because that is the objective. As mentioned in the introduction to this article, the issue of disclosure of clarity enhancement had some damaging effects on the trade during the 1990s. In fact, many of these issues have continued into the new millennium.

Diamond. Clarity enhancement of diamonds by fracture filling began in the late 1980s, with the first comprehensive article on the subject published by Koivula et al. (1989). This first article focused on the product from Yehuda Diamond Corp., the only company performing this treatment at the time. Five years later, another comprehensive article (Kammerling et al., 1994b) dealt not only with the then-current Yehuda product, but also with filled diamonds from newer players in this field, especially Koss and Goldman-Oved (figure 17).

Clarity enhancement of diamonds became a serious issue when the lack of disclosure by certain U.S. retailers led to devastating exposés in the national media (see, e.g., "Everyone's best friend," 1993). In particular, two St. Louis jewelers were accused of selling filled diamonds without disclosing the treatment ("Five on your side," 1993), which eventually led to the destruction of their business and even the tragic death of one of them ("Rick Chotin…," 1994).

The key identifying feature for fracture-filled diamonds remains the flash effect: the different colors seen when the fracture is viewed at an angle nearly parallel to its length, first in darkfield and then in brightfield. Colors seen perpendicular to the fracture are not flash colors and are due to diffraction within feathers that most often contain only air. The 1994 article by Kammerling et al. showed that while the identifying features of filled diamonds from the three manufacturers were similar in many respects, there were differences in the intensity and hue of the flash colors from one product to another; however, no flash effect was sufficiently unique to identify a particular manufacturer. This was also the case with other microscopic features typical of filled stones, such as trapped gas bubbles, areas of incomplete filling (particularly at the surface), and cloudy fillings.

A number of other studies concerning clarity enhancement of diamonds were published during the first half of the 1990s (Scarratt, 1992; Nelson, 1993, 1994; Sechos, 1994; McClure and Kammerling, 1995). All were aimed at disseminating the identification criteria for this treatment to as many people in the trade as possible.

Also noteworthy was the discovery that *rough* diamonds were being filled and then shipped to Africa to be sold (Even-Zohar, 1992). This obvious

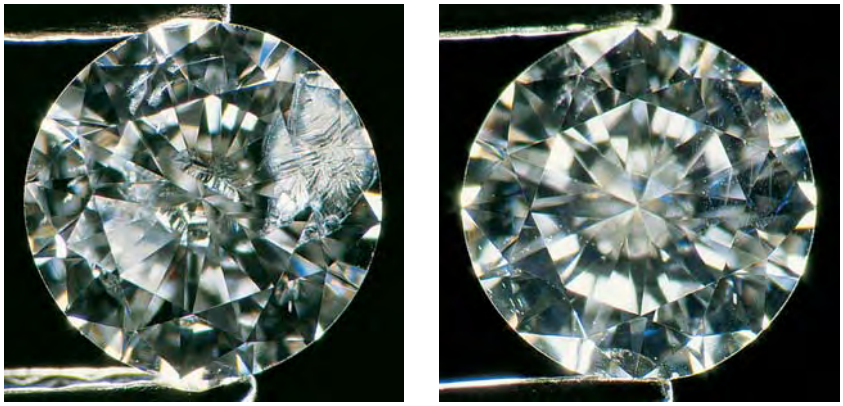


Figure 17. Clarity enhancement of diamonds can be very effective, as illustrated by these before (left) and after (right) views of a 0.20 ct diamond that was treated by the Goldman-Oved Company. Photomicrographs by Shane F. McClure.

attempt to defraud buyers was quickly condemned by the diamond industry, and a resolution was eventually passed by the combined leadership of the International Diamond Manufacturers Association and the World Federation of Diamond Bourses that prohibited the filling of rough or the selling of filled rough (Even-Zohar, 1994).

Filled fractures were observed in several colors of fancy diamonds, including yellow (McClure and Kammerling, 1995), pink (Reinitz, 1997a), and brown (Sechos, 1995). The yellow-to-orange flash effect normally seen in darkfield illumination was almost not visible in the yellow diamond, although the dark blue brightfield flash color stood out quite nicely on the yellow background. The color appearance of the pink diamond improved as the numerous large fractures in the stone were made transparent by the treatment.

Variations in the flash effect were reported occasionally. One diamond showed a vivid blue flash color that resembled a dark "navy" blue ink splotch (Hargett, 1992a). In some filled diamonds, the flash colors are so subtle as to be easily overlooked; in such cases, the use of fiber-optic illumination is invaluable (Kammerling and McClure, 1993a). Conversely, another note reported flash colors that were so strong as to appear pleochroic in polarized light (Johnson, 1996b).

Johnson et al. (1995) reported a filling material with an unusual chemical composition: It contained thallium in addition to the more typical trace elements found in fillers, Pb and Br. They speculated that this might have been one of the earlier filled diamonds, as there were rumors that some of the first fillers contained thallium.

Even though much has been published about the inability of diamond filler materials to withstand heat, gemological laboratories commonly see filled diamonds that were damaged during jewelry repair procedures. In almost all cases seen to date, the jeweler was not told that the stone had been clarity enhanced and did not take the time to look at the diamond with magnification for the telltale signs. Such were the circumstances with a 3.02 ct diamond that was eye clean before the jeweler started repair work on the ring in which it was mounted (Hargett, 1992b). The large, eye-visible fractures that appeared in the center of the stone when the mounting was heated created a difficult situation for the jeweler. This scenario has been played out many times since then. A later report described filler material that actually boiled out of the fractures and deposited on the surface of the diamond in small droplets (Johnson and McClure, 1997a).

Emerald. There has never been a better example of the impact that a gem treatment can have on the jewelry business than what occurred with emeralds during the last decade. Even though emeralds have undergone some sort of clarity enhancement for centuries (figure 18), not until the 1990s did this treatment and its disclosure become a critical issue for the trade. A series of unfortunate events created a loss of consumer confidence, particularly in the United States, that had a devastating effect on the emerald market. Bad press in the form of high-profile lawsuits, and local and national television exposés on programs such as *Dateline NBC* ("Romancing the stone," 1997), contributed to this problem, but they were certainly not the only cause. One noted emerald dealer pointed out that this lack of consumer confidence started in 1989, when a synthetic resin called "palm oil" or "palma" became prevalent for fracture filling in Colombia (Ringsrud, 1998). He attributed the problem to the fact that this substance, which has an R.I. of 1.57, hides fractures too efficiently and is notoriously unstable. He estimated that in approximately 20% of the stones treated with "palm oil," the filler would turn white and become translucent in only a

Figure 18. Clarity enhancement of emeralds has been done for centuries, but it became a significant issue for the trade in the 1990s. Many saw the dramatic effect this treatment can have on an emerald for the first time with the publication of photos that showed stones before enhancement (left) and after (right). Photos by Maha Tannous.

few months, so that fractures that had been virtually invisible became obvious to the unaided eye. One can only speculate as to the potential impact of such deterioriation on the consumer, who probably was not told the emerald had been filled at the time of purchase.

These and other aspects of the issue were heavily debated in the trade press (see, e.g., Bergman, 1997; Federman, 1998; Schorr, 1998). Three major concerns surfaced: (1) what types of fillers were being used, (2) how permanent or durable each filler was, and (3) how much filler was present in any given stone.

The types of fillers being used for clarity enhancement of emeralds have expanded dramatically during the last decade. Kammerling et al. (1991) noted that in addition to traditional fillers such as cedarwood oil, treaters had started to use epoxy resins, the most popular of these being Opticon. This article also mentioned that proprietary filling substances were being developed by several other companies (Zvi Yehuda Ltd. of Israel, CRI Laboratories of Michigan, and the Kiregawa Gemological Laboratory of Japan).

Since that time, many other fillers have been introduced, and the infamous "palm oil" was identified as probably being the liquid epoxy resin Araldite 6010 (Johnson et al., 1999). Treaters also started to use hardened epoxy resins, with the idea that they would be more durable than the liquid materials, which tended to leak out over time. The formulas for these resins are considered proprietary and carry names such as Gematrat, Permasafe, and Super Tres.

The durability of the individual fillers remains the subject of ongoing research. There is little debate as to the nonpermanence of "palm oil" or cedarwood oil (see, e.g., Kammerling et al., 1991; Federman, 1998; Kiefert et al., 1999). However, those who use other fillers have made various claims regarding their ability to hold up under normal conditions of wear and care. In fact, this feature has been the focus of marketing efforts by several of the treaters who offer hardened resins (Johnson and Koivula, 1997b; Weldon, 1998a; "New type of epoxy resin," 1998; Fritsch et al., 1999a; Roskin, 1999).

An interesting development during this debate came when many in the industry claimed that a desirable feature of a filler would be the ability to remove it. Because some of these resins decompose and turn white or cloudy with time, dealers recognized that they eventually would need to be removed so that the stones could be retreated. This was a valid concern, as attempts to remove these unstable fillers often have been unsuccessful (Themelis, 1997; Hänni, 1998).

Also during this decade, a number of laboratories maintained that they could comfortably make the distinction between specific types of fillers and began to offer such a service (see, e.g., Hänni et al., 1996; Weldon, 1998c; Hänni, 1998, 1999; Kiefert et al., 1999). Others believe that while these fillers may be separated into broad categories, it can be difficult or even impossible to identify mixed fillers or stones that have been treated multiple times with different fillers (Johnson et al., 1999).

In light of this debate, many have suggested that the amount of filler in a given emerald is perhaps more important than the kind of filler used (Johnson and Koivula, 1998b; Drucker, 1999). Thus, many laboratories offer a service that classifies the degree of enhancement. In most cases, the system uses four or more classifications, such as *none*, *minor*, *moderate*, and *significant* (see, e.g., McClure et al., 1999).

The criteria used to detect fillers in emeralds have been described at length by various researchers (see, e.g., Johnson and Koivula, 1998b; Hänni, 1999). These criteria primarily consist of

flash effects (figure 19), incomplete areas of filling or gas bubbles (figure 20), and whitish or deteriorated filler within the fractures—all of which can be seen with magnification.

Additional information about emerald fillers was published throughout the decade. Hughes Associates, the manufacturer of Opticon, reported that the refractive index of Opticon can range from 1.545 to 1.560, depending on the amount of hardener added (Koivula et al., 1993b). The chemistry of fillers was closely examined to determine if it could be an aid in identification (Johnson and Muhlmeister, 1999). Unfortunately, the answer was *no*. The new hardened filler Permasafe was characterized by Fritsch et al. (1999a). Early on, two Brazilian dealers reported that some treaters were adding a green coloring agent to Opticon (Koivula and Kammerling, 1991a), a practice that is not acceptable in the trade.

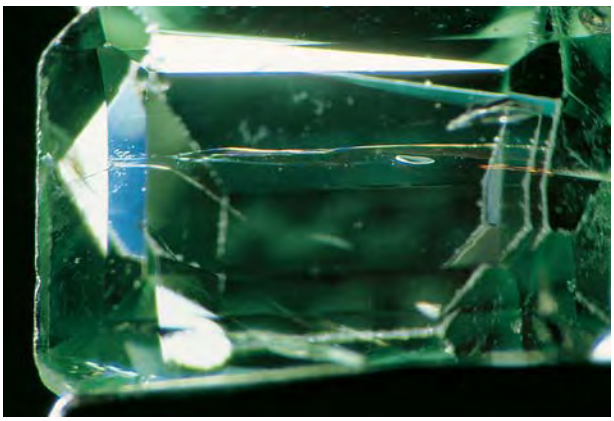


Figure 19. The flash effect is one feature that can be used to identify if an emerald has been filled. The two most common colors, orange and blue, are seen in this stone in a fracture that is otherwise almost invisible. Photomicrograph by Maha Tannous; magnified 15×.

Other Gem Materials. Of course, it was inevitable that clarity enhancement would find its way into other gem species. We know of two reported incidences in the '90s: one in alexandrite (Kammerling and McClure, 1995a), and the other in a pyrope-almandine garnet (Kammerling and McClure, 1993b).

IMPREGNATION

Impregnation of porous gem materials with different kinds of polymers to improve their appearance or durability has been widespread for many years. The 1990s saw major developments concerning the use of this treatment technique on a number of important gem materials.

Jadeite. The most significant gem material affected by impregnation during the last decade was jadeite. The treatment process, which is often referred to as "bleaching," caused such an uproar in the jade industry that jadeite sales in Japan fell as much as 50% over a three-month period in the beginning of the decade ("New filler threatens jadeite sales in Japan," 1991).

"Bleaching" actually involves a two-step process. First the jadeite is immersed in an acid to remove the brown iron oxide staining that is so common in this material. This staining gives the stone a brown coloration that is less desirable and therefore detrimental to its value. The result after "bleaching" is a color such as pure green or green and white. Unfortunately, this process leaves behind voids in the structure of the jadeite, which make the grain boundaries of the aggregate material readily visible, and many fractures may appear. Not only do these voids and fractures adversely affect the translucency of the gem material, but they also can affect the durability of the jadeite, so that it is more susceptible to breakage (Fritsch et al., 1992).

It is because of these adverse effects that the sec-

Figure 20. Another feature that can help determine whether an emerald has been filled is the presence of gas bubbles or unfilled areas within a very low relief fracture. Photomicrograph by Shane F. McClure; magnified 22×.

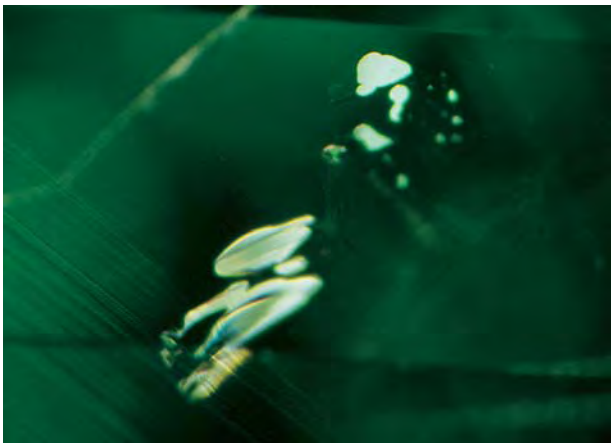
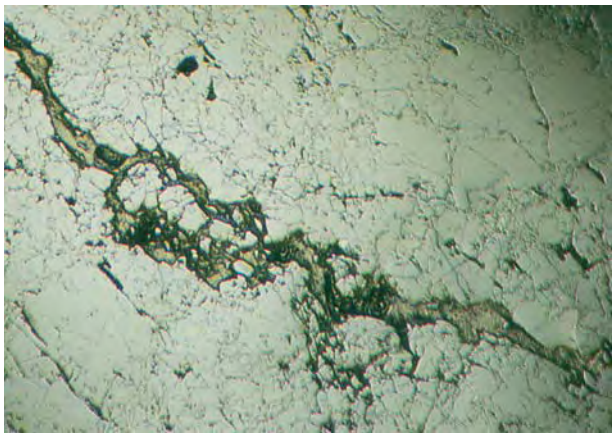


Figure 21. All of these jadeite cabochons have been bleached and subsequently impregnated with a polymer to improve their appearance. The overall result is usually quite effective. Photo by Maha Tannous.

ond step of the process is necessary: The "bleached" jadeite is impregnated with a polymer (usually an epoxy resin) to fill the voids and return the stone to an acceptable translucency (figure 21). This addition of a foreign material created the need for a new classification of jadeite. The bleached and polymer-impregnated material came to be known as "B jade." "A jade" refers to jadeite that has not been treated at all, and "C jade" is used for dyed jadeite.

Figure 22. Structural damage caused by the bleaching process is clearly seen in this treated jadeite. Also visible is a large fracture filled with the impregnating polymer. Photomicrograph by Shane F. McClure; magnified 30×.



The origins of this treatment lie somewhere in the mid-1980s, and an early report was given by Hurwit (1989). The beginning of the '90s saw an explosion of bleached jadeite on the market. Since no in-depth studies had been done on the material at that time, there were no procedures in place to identify it. Once this became widely known, and all jadeite became suspect, the price of jadeite plummeted.

The first comprehensive study on the identification of bleached and impregnated jadeite was published by Fritsch et al. (1992). These researchers found that the only conclusive way to detect if a piece had been treated was to examine its infrared spectrum for the telltale "signature" of the polymer filler. Subsequently, a number of other identification methods were described, such as the use of X-ray photoelectron spectroscopy (Tan et al., 1995) and diffuse reflectance Fourier-transform infrared (FTIR) spectroscopy (Quek and Tan, 1997), as well as the use of a simple drop of acid (described in Fritsch et al., 1992, and elaborated in Hodgkinson, 1993). Some of these methods were even used to identify polystyrene as one of the polymers used (Quek and Tan, 1998). However, infrared spectroscopy remains the easiest test to perform, provided one has the necessary equipment. By the end of the decade, several jadeite dealers had purchased an FTIR spectrophotometer so they could personally test all the jadeite they handle.

It was also noted early on that the structural damage caused by the bleaching process could be seen in reflected light with a microscope (figure 22—Ou-Yang, 1993; Moses and Reinitz, 1994; Johnson and DeGhionno, 1995). This surface texture has been referred to as having an etched or honeycomb-like appearance, which is a manifestation of the gaps or voids left between the individual grains in the jadeite structure. Articles were published on the use of a scanning electron microscope to study and document this phenomenon so that it might be used as an aid in identification (Tay et al., 1993, 1996).

Tests conducted on the durability of this material found that long-term exposure to detergents could damage or remove some of the filler. Also, heating at 250°C can turn the treated jadeite brown (Johnson and Koivula, 1996b).

Some particularly unusual examples were reported: a bangle bracelet with internal gas bubbles generated by the filling of cavities that were created when the acid etched out carbonates within the

Figure 23. These turquoise cabochons were treated by the Zachery process, which decreases the porosity of the material, making it less likely to discolor with time and wear. Photo by Maha Tannous.

jadeite (Koivula, 1999), a necklace that had a mixture of treated and untreated jadeite beads (Kammerling, 1995b), and the first reported instance of a bleached and polymer-impregnated lavender jadeite (Kammerling et al., 1994a).

The most important thing for the gemologist to remember about this treatment is that it can be identified conclusively only by sophisticated means such as infrared spectroscopy. There may be some indications, such as a yellow fluorescence, low specific gravity, or coarse surface texture, but these do not prove that a piece of jadeite has been treated.

Turquoise. Turquoise is notorious for being impregnated. Because its inherent porosity makes it subject to discoloration from wear, treatment is very common. As one might expect, impregnation of turquoise with plastics (Kammerling, 1994a,b) and oils (Koivula et al., 1992g, 1993c) was still prevalent in the 1990s.

The most significant turquoise treatment that came to light in the '90s may not be an impregnation at all. Called Zachery treatment after the man who developed it, this process actually was introduced in the late 1980s, although the first major study did not appear until 1999 (Fritsch et al., 1999b). During this decade, millions of carats of Zachery-treated turquoise entered the trade (figure 23).

The process is still a closely guarded secret, so exactly how it effects the change in turquoise is not completely understood. We do know that Zachery treatment reduces the porosity of turquoise, but there is no evidence that it adds any polymers or other foreign material. The end result is turquoise that does not absorb oils or other liquids during wear and therefore does not discolor, as most natural turquoise does in time. The turquoise can be treated without changing its original color, or the color can be darkened, depending on the wishes of the client.

Regardless of the actual enhancement mechanism, the only way to prove conclusively that an individual piece of turquoise has been treated by this process is through chemical analysis, since Zachery-treated turquoise usually has an elevated potassium content. Visual indications of this treatment include a slightly unnatural color, a very high polish, and blue color concentrations along surface-reaching fractures (figure 24).

Opal. While there were no new advances in the impregnation or "stabilization" of some kinds of matrix opal, which has been a common practice for many years, there were a few other notable developments with regard to opal.

The hydrophane opal mentioned in the Dyeing section, which was treated to resemble Australian black opal, was also impregnated with a plasticized liquid to seal the porosity and improve the transparency after the dyeing process (Koivula et al., 1992c).

Impregnated synthetic opal appeared on the market during this decade. It is not difficult to identify, because the specific gravity (around 1.80–1.90) is

Figure 24. Although Zachery treatment can be proved only through chemical analysis, the presence of color concentrations along fractures in the turquoise is a good indication. Photomicrograph by Shane F. McClure; magnified 10×.

too low for untreated material (Kammerling and McClure, 1995b; Kammerling et al., 1995; Fritsch, 1999). However, controversy arose when some in the trade objected to the use of the term *synthetic* in association with this material, because it is impregnated with plastic. This nomenclature issue is still being investigated and discussed.

SURFACE COATINGS

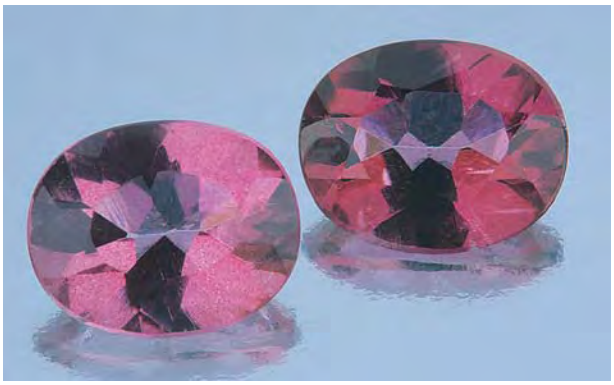
Changing the color of gem materials by the use of colored surface coatings was a very popular treatment throughout the 1990s, as it has been for centuries. We continue to see different kinds of coatings on various gems, sometimes to imitate more valuable stones and sometimes to create a unique look not associated with a natural material.

Plastic remained a popular coating substance. To improve transparency and luster, treaters used both plastic and wax to coat **jadeite** (Koivula and Kammerling, 1990b, 1991i). Plastic also provided stability to fossilized **ammonite** that was unstable due to natural frost shattering in surface deposits (Koivula and Kammerling, 1991h). A transparent colored plastic coating was used to impart an emerald-like appearance to beads fashioned from light **green beryl** (Crowningshield, 1995a). The presence of air bubbles and abnormal surface irregularities visible with magnification, as well as reaction to a "hot point," are the best means to identify this type of coating.

The surface coating of colorless **topaz** was widespread, with different processes being used by the end of the decade. Orange, pink, and red material (see, e.g., figure 25) showed a spotty surface coloration (detected with low magnification) that was easily scratched by a sharp object. Although the process was originally represented as diffusion treatment, these colors (unlike the green-to-blue surface-treated topaz described in the earlier Diffusion Treatment section) were probably produced by sputter coating (Johnson and Koivula, 1998d).

Thin metallic coatings remained popular for treating both **quartz** and **topaz**, as crystals and as faceted stones (figure 26). Microscopic examination of gold-coated blue to greenish blue "Aqua Aura"–treated samples, which made their debut in the late 1980s, revealed unnatural coloration at facet junctions and an irregular color distribution on some facets (figure 27—Koivula and Kammerling, 1990a; Kammerling and Koivula, 1992). Durability testing of these gemstones showed that even though the coating is relatively hard and chemically inert (Koivula and Kammerling, 1990a), care must be taken to avoid damage during jewelry manufacturing or repair (Koivula and Kammerling, 1991d). New colors and effects were created in coated quartz by using different combinations of metallic elements. These included purple, yellow, green, and red hues created by Au, Bi, Pb, Cr, Ti, and other elements (Johnson and Koivula, 1996a), as well as a "rainbow" iridescence that was reportedly caused

Figure 25. These topazes were originally represented as being diffusion treated, but they actually were coated with a color layer that was easily scratched off. The pink stone is 3.19 ct and the red one, 3.29 ct. Photo by Maha Tannous.



by an Ag/Pt coating (Koivula and Kammerling, 1990e). A colorless sapphire with a yellowish orange coating that was seen in the early 1990s also might have been treated by such a process (Moses and Reinitz, 1991).

The demand for certain colors of **sapphire** led to the resurfacing of some "old tricks" in Sri Lanka that used organic compounds to create surface coatings (Koivula and Kammerling, 1991b). Pale or colorless rough was turned yellow by boiling in water (sometimes with wax added) that contained the branches or bark of a local tree. Some Sri Lankans took a similar "low-tech" approach to imitate pink sapphire rough: The treater placed the pale or colorless sapphire in his mouth along with a local berry, chewed the berry to create the pink coating, and followed this by smoking a cigarette (which reportedly improves the durability of the coating). These treatments may seem unimportant, but to the gem buyer alone in a remote area of Sri Lanka, knowing about them could mean the difference between a successful trip and a disaster.

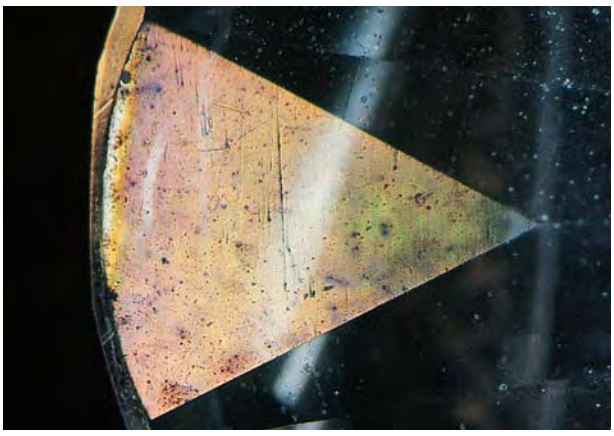
Coated **diamonds** were still encountered in the laboratory during the 1990s, although less frequently. One such stone showed a brownish purple-pink color that rarely occurs naturally in diamonds (Crowningshield and Moses, 1998). Although the exact nature of the coating substance could not be identified, its speckled appearance over the entire stone suggested a sputtering process. **Diamond-like carbon** (DLC)—an amorphous brown material with a hardness between that of diamond and corundum—was used experimentally at the beginning of the decade to coat several gemstones, which resulted in greater durability (Koivula and Kammerling, 1991e). More recently, DLC was identified on a treated-color "black" diamond by Raman analysis; researchers used the same method to tentatively identify a carbide compound on a treated-color green diamond (Reinitz et al., 2000a).

New **pearl** coatings presented some significant identification challenges in the 1990s. A strand of lustrous black circled cultured pearls was found to be coated with a form of silicone called polydimethyl siloxane (Hurwit, 1999). A peculiar smoothness, sticky feel, and slight anomalous reaction to a thermal reaction tester were the only clues to the presence of the coating; advanced techniques were needed to identify it. Mabe assembled blister pearls also were coated, but Hurwit (1991) reported that the lacquer coating was applied to the plastic dome *under* the layer of nacre. The effect was to improve the luster and overtone of the white mabe pearls. A spotty, uneven color distribution suggested the presence of an enhancement, but only by disassembling a sample could the coating be confirmed.

Figure 26. Aqua Aura treatment was still used extensively on quartz (the two inside stones) and topaz (the two outside stones) throughout the '90s. Photo by Robert Weldon.

To produce a dark background and thus bring out the play-of-color, **opal** was subjected to several coatings, including: (1) black paint on the base of diaphanous opal from Australia (Brown et al., 1991),

Figure 27. Aqua Aura treatment is easily detected by the presence of unnatural surface coloration on the facets of a stone. Photomicrograph by John I. Koivula; magnified 12×.



(2) a dark plastic-like material on portions of a Mexican opal (Koivula and Kammerling, 1990c), and (3) sugar-treated opal that appeared to be further coated with a plastic-like substance (Koivula and Kammerling, 1990d). All of these coatings were readily apparent with microscopic examination.

Two other relatively isolated occurrences of coatings deserve mention. A brittle glass-like coating was responsible for the dark violet-blue color of some drilled **quartz** beads (Kammerling and McClure, 1994). This coating, possibly applied by an enameling process, was identified though a combination of microscopic examination of the drill holes, hardness testing, and advanced techniques. Koivula et al. (1992a) noted that acrylic spray could be used to enhance the luster of massive gem materials such as **lapis lazuli** and **jadeite**. Such a coating is easily identified: With magnification, slight concentrations are seen in surface irregularities, and the acrylic can be easily removed if it is rubbed with a cotton swab that has been dipped in acetone.

It is interesting to note that the use of coatings has spread to some laboratory-grown materials. A company in northern California trademarked the name Tavalite (Johnson and Koivula, 1996d) for **cubic zirconia** that had been treated with an optical coating. The process created six different colors that had a different appearance in reflected and transmitted light. This product was very easy to identify, in that it does not resemble any other material.

CONCLUSION

It can safely be said that events of the 1990s changed the attitude of the entire industry toward treatments and disclosure, which today constitute the single most important issue facing the trade. Identification of some of the significant treatments—such as glass-filled rubies, HPHT-processed diamonds, and a variety of irradiated gem materials—continues to challenge many gemologists. Within the last year, we have already seen significant new developments in the laser drilling of diamonds (McClure et al., 2000), as well as in the material used to fill fractures in diamonds (Shigley et al., 2000b). In addition, there has been recent talk of new filling processes that will bring true clarity enhancement to higher-refractive-index colored stones such as ruby, sapphire, and alexandrite (Arthur Groom, pers. comm., 2001). Also, the technology being used to create the "diffusion treated" blue-green topaz can be applied to other gem materials, and it is likely that some of these will reach the market in the future. One of the authors (SFM) has already seen colorless quartz turned pink by this process. All of these developments will undoubtedly create more identification challenges.

Some of the issues regarding disclosure may not have solutions that will be agreeable to everyone in the industry. However, there were a number of meetings in the latter half of the '90s at which leaders of prominent gemological laboratories and trade organizations worldwide met to establish better communications and greater consistency in reporting terminology. These meetings illustrate the determination of the jewelry industry to address these issues and find solutions that will benefit members of the trade and consumers alike.

The 1980s retrospective article asked the question, "What new treatments might face us in the not-too-distant future?" Yet technological advances in the last 10 years have produced treatments, such as removing the color from brown diamonds, that most of us would not have thought possible at the beginning of the decade. Without a doubt, technology will continue to advance at an even faster rate during the next decade. The only thing we can guarantee is that there will be no end to fresh challenges in treatment identification and disclosure as we enter the new millennium.

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Key to abbreviations: *Australian Gemmologist* = *AusG*; *Gems & Gemology* = *G&G* (Gem News = GN, Gem Trade Lab Notes = GTLN); *Jewelers' Circular Keystone* = *JCK*; *Jewellery News Asia* = *JNA*; *Journal of Gemmology* = *JofG*; *Professional Jeweler* = *ProJ*.

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SYNTHETIC GEM MATERIALS AND SIMULANTS IN THE 1990S

By John I. Koivula, Maha Tannous, and Karl Schmetzer

The 1990s witnessed important developments in the commercial viability of gem-quality synthetic diamonds. Improvements in, and new applications for, existing synthesis pr ocesses in the production of colored stones such as ruby, sapphire, emerald, quartz, and alexandrite have had an impact as well. The development and commercialization of a variety of new synthetics and simulants, such as synthetic moissanite and flux-grown synthetic spinel, also played an important role in shaping the past decade for the gem and jewelry industry.

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The decade of the 1990s was probably the first in modern gemological history where advances in the production and identification of synthetics and simulants were overshadowed by treatment processes and the detection of enhancement in gem materials. This was due primarily to the emergence of new diamond treatments (i.e., color enhancement and decolorization) and to the proliferation and further development of existing techniques for altering the apparent clarity of gemstones (e.g., laser drilling of diamonds, "glass" filling of rubies, oiling, and heat treatment), as discussed by McClure and Smith (2000) elsewhere in this issue. However, some important new synthetics were developed, others were improved, and the presence of so many synthetic gem materials and simulants had a significant impact on the trade (see, e.g., figure 1).

Although synthetic diamond continued to cause great concern in the gem industry during the '90s, perhaps even more important commercially was the introduction of a new diamond simulant: near-colorless synthetic moissanite. For most skilled gemologists, synthetic moissanite is easy to identify because of its nonisotropic optical character and other distinctive properties; however, it reads as "diamond" on most conventional diamond testers. The alarm it quickly generated in the trade illustrates the panic that can result from a perceived threat to the diamond industry. And the level of concern that continues to exist points out the general lack of even basic gemological knowledge among many in the trade, as well as the danger inherent in relying on testing instruments that may give inaccurate results.

Both Russia and China were important sources of synthetic colored gem materials in the 1990s. In particular, the collapse of the former Soviet Union made available equipment and intellectual resources that had previously been

Figure 1. Numerous synthetics and simulants were either introduced or, in most cases, gained or maintained a strong commercial presence during the 1990s. These include, from the top (left to right): Row 1—1.09 ct flux-grown synthetic red spinel, 1.14 ct Czochralski-pulled synthetic blue sapphire, 1.29 ct synthetic citrine, 1.81 ct synthetic red beryl, 0.96 ct Tairus hydrothermal synthetic emerald; row 2—0.83 ct flux-grown synthetic blue spinel, 1.02 ct black and 1.48 ct white Gilson synthetic opal, 0.73 ct hydrothermal synthetic amethyst; row 3—0.43 ct synthetic moissanite, 1.15 ct Tairus hydrothermal synthetic ruby, 0.66 ct Czochralski-pulled synthetic alexandrite, 0.58 ct De Beers experimental synthetic diamond. Photo by Maha Tannous.

devoted to (and developed for) military research. For decades, the Russians had been working on advances in various methods of crystal growth for electronics, communications, and laser applications. These efforts led to important developments in hydrothermal crystal growth (from hot aqueous solutions on oriented seed crystals): synthetic ruby and sapphires, synthetic quartz (amethyst, citrine, and ametrine), and synthetic emerald and alexandrite, as well as synthetic spinel, forsterite (a tanzanite imitation), and a number of other gem materials, all of which are discussed below. A general review of synthetic crystal growth and the production of artificial gem materials (both colored stones and diamonds) in Russia during this decade is provided by Balitsky (2000).

While some Chinese synthetics have been studied gemologically, few details are available on production figures or growth facilities. However, we do know that the Chinese introduced a synthetic hydrothermal emerald into the marketplace (Schmetzer et al., 1997) and have been heavily involved in the production of other synthetics. Although other countries such as Japan and the U.S. also had significant synthesis activities, Russia and China were dominant in colored stone synthesis during the decade.

This article provides a general overview of developments in the production and identification of synthetic diamond, moissanite, ruby, sapphire, emerald and other beryls, quartz, alexandrite and chrysoberyl, spinel, forsterite, opal, and other synthetics, as well as simulants and imitations. Given space limitations and the focus of the *Gems & Gemology* audience, review of the published literature—during the period 1990 to 1999—has been confined mainly to information that appeared in gemological journals on materials that have been seen commercially in the jewelry trade. (See Nassau, 1997, for a general review of the chronology of the growth and commercialization of synthetic gem materials, which includes developments up to the mid-1990s.) Readers are advised to use the present article as a "guide" to the literature of the last decade, and to consult the cited references for details on each subject, particularly regarding methods of identification.

SYNTHETIC DIAMOND

Single-Crystal Synthetic Diamonds. From the volume of published literature, the most important developments in gem synthesis would appear to have been in the area of synthetic diamonds.

In 1990, De Beers announced that the largest synthetic diamond to date was a 14.2 ct crystal grown for experimental purposes at their Diamond Research Laboratory in Johannesburg, South Africa (Koivula and Kammerling, 1990b). The yellow crystal, reportedly of "good" industrial quality, took more than 500 hours to grow under high-pressure/high-temperature (HPHT) conditions. Since that time, one of us (JIK) has seen 30+ ct yellow to brownish yellow synthetic diamond crystals—with areas of gem quality—that were grown experimentally by De Beers. These synthetic diamonds were marketed for industrial applications in

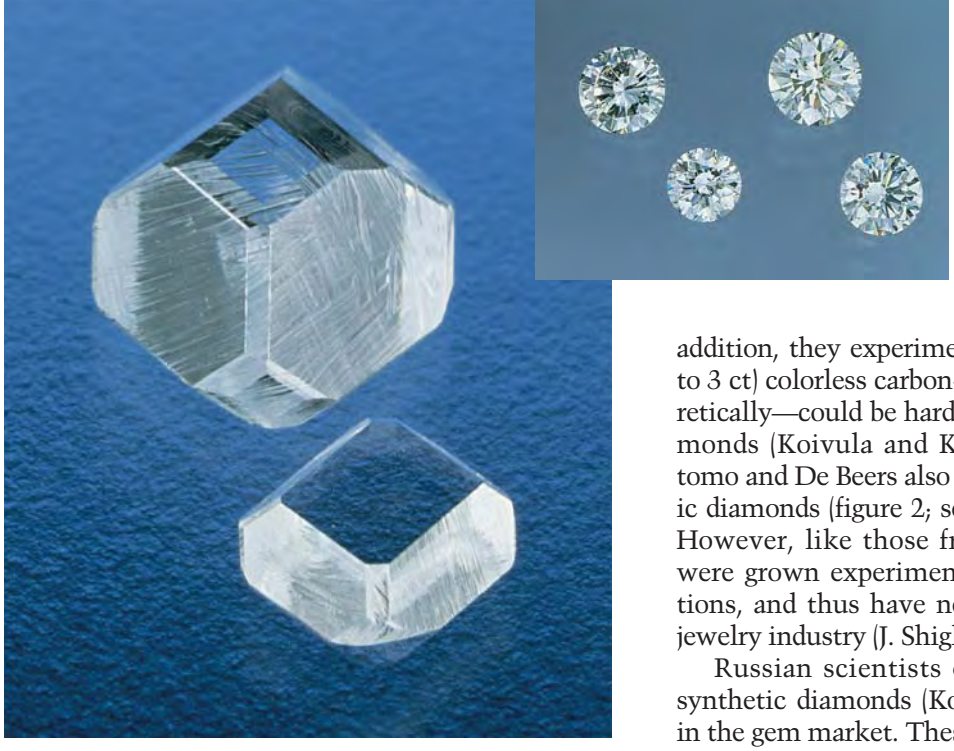


Figure 2. Both Sumitomo and De Beers grew near-colorless synthetic diamonds for experimental purposes. The faceted De Beers near-colorless synthetic diamonds shown here (inset) weigh 0.41 to 0.91 ct. The two Sumitomo synthetic diamond crystals (0.23 and 1.25 ct) exhibit a cuboctahedral form, which is typical of synthetic diamonds from all known manufacturers. Left, photo © GIA and Tino Hammid; inset photo © GIA.

1993, at which time the largest crystal weighed 34.80 ct and required more than 600 hours of growing time. Note, however, that the gem-quality synthetic diamonds that were commercially available in the 1990s were much smaller (see below). Most synthetic diamonds are yellow, often with brown overtones; the color is associated primarily with the presence of nitrogen. The 1990s saw experimentation with, and limited production of, diamonds with impurities such as nickel and cobalt (Kanda, 1999), as well as boron (Rooney et al., 1993; Reinitz, 1999b). It was also discovered that the typical brownish orange to yellow synthetic diamonds could be treated to create red to brownish red colors (Moses et al., 1993).

It is clear, however, that the economic production of *near-colorless* synthetic diamonds in a size and quality suitable for jewelry was at least one of the goals explored by diamond synthesizers during the last decade (Rooney et al., 1993; Shigley et al., 1997). By 1990, General Electric had demonstrated that they could grow near-colorless type IIa diamonds exceeding 1 ct using a transition-metal flux to prevent the incorporation of nitrogen and boron impurities (Shigley et al., 1993b). In addition, they experimentally synthesized large (up to 3 ct) colorless carbon-13 diamonds, which—theoretically—could be harder than carbon-12 based diamonds (Koivula and Kammerling, 1991b). Sumitomo and De Beers also grew near-colorless synthetic diamonds (figure 2; see, e.g., Shigley et al., 1997). However, like those from General Electric, they were grown experimentally for high-tech applications, and thus have not been encountered in the jewelry industry (J. Shigley, pers. comm., 2000).

Russian scientists did produce near-colorless synthetic diamonds (Koivula et al., 1994b) for sale in the gem market. These were grown as cuboctahedral crystals in a molten metal flux by a belt-type apparatus. For some time during the '90s, Tom Chatham (Chatham Created Gems, San Francisco) attempted—unsuccessfully—to achieve commercial production via presses in Russia and the U.S.

Nevertheless, there was greater availability of gem-quality synthetic diamonds in the course of the decade. Not only did the Thai-Russian joint-venture company Tairus offer limited quantities of loose synthetic diamonds, but they also began to promote yellow Russian synthetic diamonds set in rings and pendants of high quality (figure 3), which were marketed by Superings in Los Angeles (Johnson and Koivula, 1996). Toward the end of the decade, visitors to the Tucson gem shows were able to purchase small quantities of Russian-produced synthetic diamonds, faceted and rough, in various as-grown and treated colors (see, e.g., Johnson and Koivula, 1999; Smith and Bosshart, 1999). However, the limited quantities of near-colorless synthetic diamonds being marketed to the trade as crystals are generally less than 0.50 ct, with the faceted goods typically less than 0.30 ct (J. Shigley, pers. comm., 2000); most are highly included. The GIA Gem Trade Laboratory also began to see synthetic diamonds submitted for reports, including a group of 18 saturated orangy yellow to greenish yellow synthetic diamonds ranging from 0.10 to 0.71 ct (Reinitz, 1999a). Note that the metallic flux inclusions, as well as yellow luminescence and phosphorescence to short-wave ultraviolet radiation, made it easy to identify this material as synthetic. The cuboctahedral crystal form is typical of gem-quality synthetic diamonds from all known manufacturers (again, see figure 2; J. Shigley, pers. comm., 2000).

To keep pace with synthesis technology, a number of reviews (Shigley et al., 1992, 1997; Nassau, 1993; Sunagawa, 1995) and gemological studies (Shigley et al., 1993a,b) were written. A wall chart focusing on the separation of natural and synthetic diamonds was published to educate members of the jewelry trade (Shigley et al., 1995). Advances in diamond synthesis will undoubtedly be monitored closely throughout the current decade.

Synthetic Diamond Thin Films. Synthetic diamond (and diamond-like carbon, or DLC) thin films can be grown by *chemical vapor deposition* or CVD (see, e.g., Spear and Dismukes, 1994; Buerki, 1996). Typically deposited as a polycrystalline or drusy layer, their use as coatings on gems is discussed in the "Treatments" article in this issue (McClure and Smith, 2000). Dr. E. Fritsch had two faceted diamonds (0.33 and 0.36 ct) and a 1.15 ct piece of rough coated with a thin film of boron-bearing blue synthetic diamond by low-pressure hot-filament synthesis (Koivula and Kammerling, 1991a). In this experiment, the facet junctions were not covered very well and the resulting product conducted electricity better than natural blue diamonds. In 1992, a 2-mm-high, gem-quality crystal of CVD-grown synthetic diamond was seen (Koivula et al., 1992e), and in 1995 production of a 1,600 ct disk, 28 cm in diameter and 1.5 mm thick, was announced (Klages, 1995). Subsequently, Dr. E. Fritsch saw a parure set with drusy CVD synthetic diamond (Johnson and Koivula, 1997c), so the jewelry potential of this material was finally realized (Winter and Gäbler, 1998). It continues, however, to be extremely limited.

Figure 3. Fashioned Russian-made yellow synthetic diamonds were mounted in platinum and marketed as fine jewelry. Courtesy of Superings; photo by Shane F. McClure.

Figure 4. One of the most important simulants introduced this decade was near-colorless synthetic moissanite. These two 6.5 mm synthetic moissanites (1.74 ct total weight) are set in 18K gold earrings. Courtesy of Charles & Colvard.

SYNTHETIC MOISSANITE AND RELATED MATERIALS

In the late 1990s, near-colorless synthetic moissanite (silicon carbide; figure 4) was offered commercially as a diamond simulant (Nassau et al., 1997; Nassau, 1999; Chalain and Krzemnicki, 1999). While one of us (JIK) has known of synthetic moissanite as small faceted stones for over three decades, the earlier samples were strongly colored in shades of blue and green, and posed no real threat to the diamond trade. However, near-colorless synthetic moissanite has generated a great deal of attention: Because its thermal properties are so close to those of diamond, it reads as "diamond" on most of the thermal probes ("diamond testers"). Nevertheless, while this material has excellent hardness (Mohs 91/4^{+}), it still is not nearly as hard as diamond. More importantly, the synthetic moissanite

currently grown for jewelry purposes crystallizes in the hexagonal crystal system and is doubly refractive (as compared to singly refractive diamond). With a birefringence equivalent to that of tourmaline, this material is easy to separate optically from diamond (see, e.g., the references cited above and Hodgkinson, 1998). Even though all of the faceted synthetic moissanite examined so far in the trade has been cut so that the optic axis is perpendicular to the table facet (which makes it easy to find the uniaxial optic figure in polarized light, but minimizes the effects of the birefringence in the table-up position), doubling can be seen by reflection when the observer focuses past the culet. Through the crown, the double refraction is quite obvious (figure 5), even with a 10× loupe.

Since the commercial introduction of near-colorless synthetic moissanite in 1997, some further technical developments on silicon carbide and related materials have been patented (see Carter et al., 1998; Hunter and Verbiest, 1998), including the use of synthetic moissanite as a coating on diamond (Nassau et al., 1999). The continuing development of these super-hard silicon carbide-related materials could be important in the production of future diamond simulants.

Figure 5. Synthetic moissanite is fairly easy to identify with a microscope or a loupe. When you look through the crown, doubling of the back facets readily reveals the doubly refractive nature of this diamond simulant. Photomicrograph by John I. Koivula; magnified 20×.

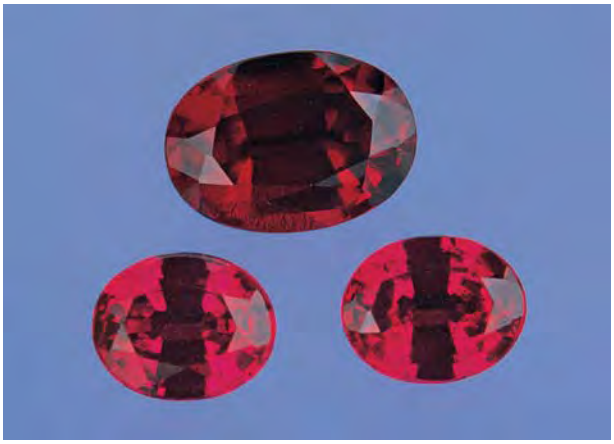


Figure 6. The production and marketing of the Novosibirsk-grown Tairus hydrothermal synthetic ruby (here, 0.43–1.05 ct) were significant developments in the synthetic gem industry. Photo by Maha Tannous.

SYNTHETIC RUBY

Hydrothermal crystal growth was an important synthesis technique for colored stones throughout the decade. The most significant development in ruby synthesis involved the combined production and commercialization of a product hydrothermally grown by Tairus in Novosibirsk, Russia (figure 6). While the hydrothermal synthesis of ruby was not new to the 1990s, improvements in the growth technique and the aggressive marketing by Tairus were significant developments. Several studies revealed that the most distinctive characteristic in these hydrothermal rubies was the presence of strong irregular growth features—striated and heavily roiled (also referred to as zigzag- or mosaic-like) patterns—which are easily seen with a microscope (figure 7) or even a 10× loupe (Peretti and Smith, 1993; Peretti et al., 1997; Sechos, 1997; Schmetzer and Peretti, 1999). These features look similar to those seen in other Russian hydrothermal synthetics, particularly synthetic emeralds.

Anhydrous crystal growth methods (those that do not use water) to synthesize corundum for commercial jewelry applications included melt techniques (Czochralski pulling and flame fusion) and flux growth. None of these techniques was new to gem synthesis in the '90s, but all produced significant quantities of synthetics that entered the gem market. As in decades past, Czochralski-pulled synthetics were sometimes represented incorrectly as "recrystallized" rubies or sapphires (Kammerling et al., 1995d; Nassau, 1995). Also as in the past, the vast majority of synthetic rubies

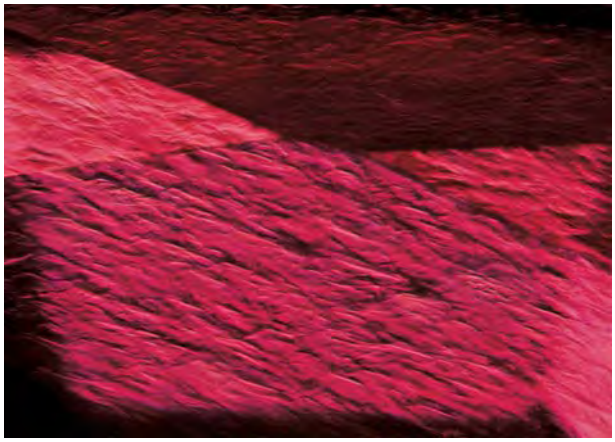


Figure 7. A zigzag-like growth structure is characteristic of some of the Russian hydrothermal synthetic rubies and sapphires examined to date. Photomicrograph by John I. Koivula; magnified 25×.

were grown by flame fusion; the same identification criteria continue to apply (i.e., gas bubbles and curved striae). Nevertheless, the number of "obvious" flame-fusion synthetics submitted to gemological laboratories suggests a distressing lack of gemological knowledge in the trade as a whole. Jewelers apparently are still finding it difficult to identify material produced by this 100-year-old technology.

For flux-grown synthetics, at the beginning of the '90s P.O. Knischka of Steyr, Austria, was producing synthetic rubies of incredible size—crystals over 5 cm long and faceted stones as large as 67 ct (Koivula and Kammerling, 1990e; see, e.g., figure 8). Identification is no problem, though, as all Knischka synthetic rubies contain characteristic glassy two-phase inclusions. With the death of Professor Knischka in the mid-1990s, production of this material apparently ceased.

The Russians also produced limited quantities of flux-grown synthetic rubies, using tungstate fluxes containing lithium and molybdenum (Henn and Bank, 1993a; Henn, 1994). Two of the distinctive internal features are triangular metallic (probably platinum) inclusions and gas bubbles, which result from the contraction of flux inclusions before they solidified.

Also introduced in the 1990s was a flux-grown synthetic ruby that reportedly was manufactured in Piraeus, Greece (figure 9). Gemological investigations (Hänni et al., 1994; Henn and Milisenda, 1994) showed that this Douros flux synthetic was virtually identical to the flux-grown Ramaura synthetic rubies that had been produced and marketed by J. O. Crystal Co. in California since the early 1980s (see Kane, 1983). This similarity included the general lack of platinum in the finished product, and the orange color of larger flux inclusions. The Douros rubies were marketed as faceted stones up to 5 ct.

Figure 8. Knischka synthetic ruby crystals were grown in relatively large sizes, as evidenced by this 40.65 ct sample. Photo by Robert Weldon.

Muhlmeister et al. (1998) demonstrated the effectiveness of trace-element chemistry (measured by energy dispersive X-ray fluorescence [EDXRF] spectrometry) in the separation of natural and synthetic rubies. Nearly all currently produced synthetics can be identified by their trace elements.

Figure 9. The properties of Douros flux-grown synthetic rubies (here the crystal is 44.74 ct and the faceted samples, 2.14–4.93 ct) closely resemble those of Ramaura synthetic rubies. Photo by Robert Weldon.

SYNTHETIC SAPPHIRE

While melt techniques also were responsible for the bulk of synthetic sapphires sold in the '90s, as with synthetic ruby the real news was their hydrothermal crystal growth in Novosibirsk and their marketing through Tairus. Peretti et al. (1997) reported on inclusions in Russian hydrothermal synthetic sapphires and rubies, while Thomas et al. (1997) described Tairus sapphires that had been doped with varying trace amounts of nickel and chromium to achieve a broad range of colors (figure 10). Growth structures (Schmetzer and Peretti, 1999, 2000; figure 11) and, as might be expected, nickel content was found to be important for identifying these synthetics. Smirnov et al. (1999) described experimental Russian hydrothermal synthetic blue sapphires that—like their natural counterpart—were colored by iron and titanium. Schmetzer and Peretti (1999, 2000) also examined a group of experimental Russian hydrothermal synthetic sapphires, and found that the yellow samples were colored by iron, that iron and titanium together produced blue, that cobalt resulted in green, that manganese caused reddish orange, and that vanadium or a combination of iron, chromium, and nickel produced material with a color change. Whether or not these hydrothermal synthetics prove to be economic remains to be seen, but the color possibilities are most interesting.

During the decade, Chatham Created Gems produced flux-grown pink synthetic sapphires (Kammerling et al., 1994), including an 884 ct crystal that was examined at GIA (Koivula et al., 1994a; figure 12). While these synthetic sapphires have essentially the same properties and inclusions as Chatham's flux-grown synthetic ruby, their lower chromium content is responsible for the pink color. A few of these pink samples contained an interesting grid-like structure of tiny inclusions under their table facets, but these were the exception rather than the rule.

Czochralski-pulled synthetic pink sapphire was grown by Union Carbide (Johnson et al., 1995), but with Ti^{3+} as the dominant chromophore (figure 13). Large stones can be cut from the pulled rods; the largest rod section examined in that study weighed 343.33 ct. These products fluoresce blue to short-wave UV, which helps separate them from natural pink sapphires when no inclusions are present. In recognition of their titanium content, these synthetic stones have been called "Ti-sapphire."

The separation of natural from synthetic colorless sapphires was also addressed in the '90s (Elen and Fritsch, 1999). If no distinguishing inclusions are present, a search in polarized light may reveal

Figure 10. Tairus marketed Russian hydrothermal synthetic sapphires in a broad range of colors that were produced by different trace-element dopants. Left = greenish blue samples, colored by Ni^{2+} and Ni^{3+} (the rough sample is 9.99 ct); center = synthetic ruby (2.17 ct) and pink sapphires, colored by Cr^{3+}; and right = yellow synthetic sapphires, colored by Ni^{3+} (the largest is 4.74 ct). Photos by M. Glas.

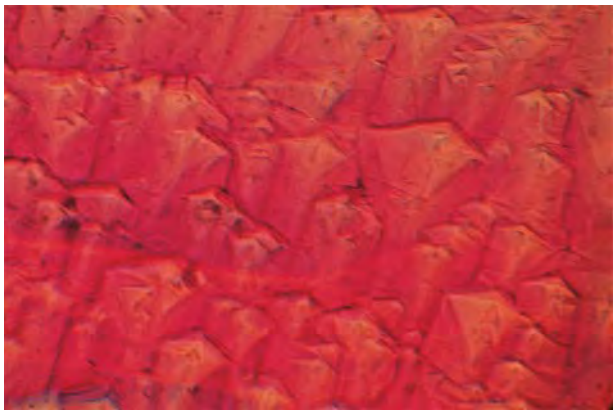


Figure 11. The hillock-like growth structure shown here in an intense pink sample appears to be a feature diagnostic of Russian hydrothermal synthetic rubies and sapphires. Photomicrograph by Karl Schmetzer; magnified 50×.

Figure 12. Chatham Created Gems produced this 884 ct flux-grown pink synthetic sapphire and the accompanying faceted material. Photo by Robert Weldon.

the so-called Plato lines that are indicative of flame-fusion growth. Short-wave UV radiation may show curved growth zoning in some colorless synthetic sapphires. EDXRF analysis revealed higher concentrations of trace elements such as gallium, iron, and titanium in natural colorless sapphires. These trace elements also cause a reduction in short-wave UV transparency, so that natural colorless sapphires appear opaque to this test, while their synthetic counterparts appear transparent (figure 14). Elen and Fritsch (1999) described a tester that was specially designed for this purpose.

SYNTHETIC EMERALD AND OTHER BERYLS

Synthetic Emerald. Although significant quantities of hydrothermal synthetic rubies and sapphires were grown during this period, the two most important hydrothermal synthetic gem materials in terms of quantity produced and availability were beryl (mainly emerald) and quartz (mainly amethyst). Hydrothermal synthetic emeralds were available from both China and Russia, although significantly more was published on the latter. Schmetzer et al. (1997) examined synthetic emeralds that emerged from Guilin, China (figure 15). They reported the presence of (1) oriented needle-like tubes (spicules) and cone-shaped voids that were typically associated with small chrysoberyl crystals (figure 16), and (2) growth and color zoning. Both of these internal features are believed to be diagnostic of this material.

Large numbers of faceted high-quality Russian hydrothermal synthetic emeralds continued to pass through gemological laboratories into the year 2000, although for the most part this product was not new. Schmetzer and Kiefert (1990) found that some natural and hydrothermal synthetic emeralds could be separated by means of infrared spectroscopy in the 3500–3800 cm^{-1} range. The exceptions were low-alkali-bearing natural (e.g., from Colombia and

Figure 13. This attractive titanium-doped Czochralski-pulled synthetic pink sapphire, here 1.20 ct, has been referred to as "Ti-sapphire." Photo by Maha Tannous.

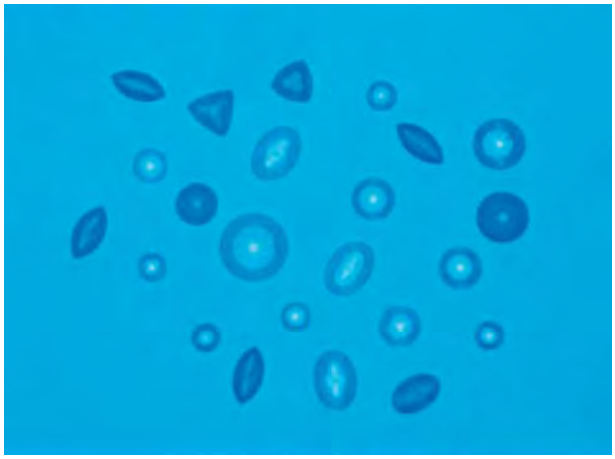
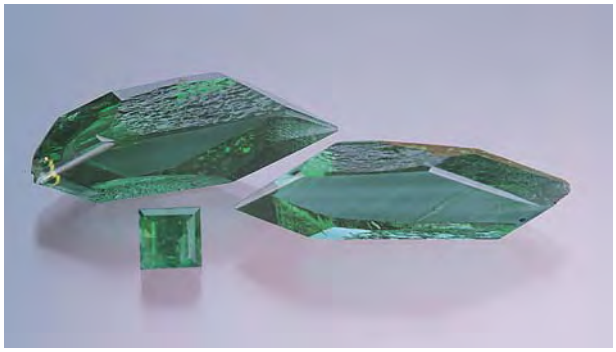


Figure 14. When viewed with the short-wave UV transparency tester, natural colorless sapphires typically appear opaque and synthetic sapphires are transparent. Photo by Shane Elen.

Nigeria) or synthetic (e.g., Russian hydrothermal) emeralds. Sechos (1997) documented some distinctive microscopic properties of Australian (Biron) and Russian hydrothermal synthetic emeralds.

Tairus also marketed an "improved" hydrothermal synthetic emerald from its Novosibirsk operation (figure 17) that showed virtually no diagnostic growth structures (Koivula et al., 1996). However, samples of this material were found to contain diagnostic clusters of tiny red-brown and white particles. Further study of the growth method and resulting growth-related properties (Schmetzer, 1996), as well as the inclusions (Schmetzer and Bernhardt, 1997), revealed that the use of seeds oriented 45° to the c-axis almost eliminated the growth features. The reddish brown inclusions were identified as iron oxides.

Figure 15. Guilin, China, is the source of these attractive hydrothermal synthetic emeralds. The crystals weigh 10.78 and 14.75 ct; the faceted piece is 1.14 ct. Photo by Maha Tannous.



Other Synthetic Beryls and Overgrowths. Russian crystal growers also manufactured and marketed hydrothermal synthetic red beryl and aquamarine during the '90s, although neither product was totally new to the decade (see, e.g., Koivula and Kammerling, 1988). Synthetic **red beryl** was described by Henn and Milisenda (1999a,c), who reported irregularly oriented subgrain boundaries as the most diagnostic property and iron, cobalt, and manganese as the colorants. A number of interesting hydrothermal synthetic **bicolored beryls** also have been produced in Russia—typically manganese-colored red beryl grown over seed plates of hydrothermal synthetic emerald. A strongly bicolored synthetic beryl crystal, with a purplish pink core and purplish blue rim (figure 18), showed very distinctive color zoning and associated orangy red and dark reddish orange pleochroism (Johnson et al., 1999b). In this instance, EDXRF analysis determined that the coloring elements were primarily manganese in the core, and manganese, chromium, and copper in the rim.

A hydrothermal synthetic **aquamarine** showed diagnostic growth structures, or cellular patterns, of subgrain boundaries (Schmetzer, 1990). At the end

Figure 16. This dense pattern of nailhead spicules and chrysoberyl crystals, usually located near the seed plate, is typical of that seen in the hydrothermal synthetic emeralds produced in Guilin, China. Photomicrograph by John I. Koivula; magnified 30×.

of the decade, Henn (1999a) described hydrothermal synthetic aquamarine from recent Russian production that contained characteristic swirl-like growth structures, and Smirnov et al. (1999) noted such patterns in similar Novosibirsk material that was marketed via Tairus.

Other manufacturers also experimented with potentially marketable colors of beryl. A synthetic pink beryl colored by titanium (Ti^{3+}) was reported by Brown (1990) and Fritsch et al. (1992). Grown in Perth, Australia, by Biron International Ltd., this synthetic had a slightly lower specific gravity than would be expected for natural morganite. Faceted examples up to 20 ct have been seen.

Relatively thin overgrowths of synthetic emerald on natural beryl were again reported in the 1990s. For example, "Emeraldolite" from France consists of opaque white natural beryl with an overgrowth produced by the flux method (Robert et al., 1990). In Russia, thin layers of hydrothermal synthetic emerald were grown on large, elongated, and rounded seeds of transparent colorless natural beryl (Henn and Bank, 1993b) that typically were not visible in the final product. Given that the hydrothermal growth technique has been used to produce many colors of synthetic beryl, there is no reason why overgrowths in other colors could not be produced.

Figure 17. These hydrothermal synthetic emeralds (0.17–0.41 ct) were newly produced in Novosibirsk during the '90s, another product marketed by the Thai-Russian joint venture Tairus. Photo by Maha Tannous.

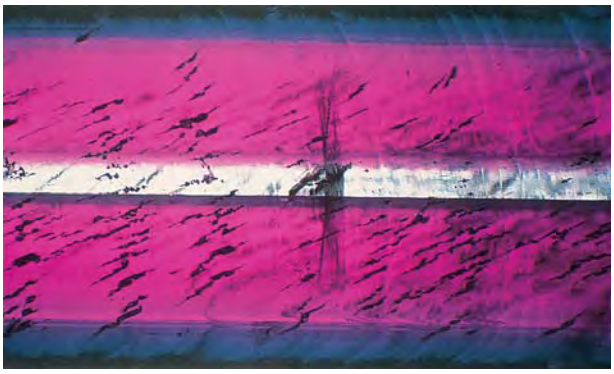
SYNTHETIC QUARTZ

Commercially, the most important variety of synthetic quartz during the '90s was hydrothermally grown synthetic **amethyst**. This material was widely used in the trade, primarily because it was so difficult to detect: Unless inclusions and characteristic twinning patterns are present, synthetic amethyst can be conclusively identified in most cases only with Fourier-transform infrared spectroscopy (Zecchini and Smaali, 1999). Even by the late 1980s, the presence of Brazil-law twinning was no longer a guarantee of natural origin, as the Russians and others were growing synthetic amethyst twinned on the Brazil law.

The synthesis process had become even more sophisticated by the late 1990s, when it was learned that round seeds were used in Beijing for the production of synthetic amethyst (Johnson and Koivula, 1998), which resulted in crystals with no obvious seed plate. Also, because of the orientation and domed shape of the seeds used by the Chinese producers, the resulting synthetic crystals have the external morphology of natural amethyst. It is unknown how much of this material is being produced, or how most of it is distributed.

While there was little new methodology for the commercial production of other varieties of hydrothermal synthetic quartz, several studies detailed the processes used to grow, and in certain instances also treat, synthetic quartz for gem applications (see, e.g., Balitsky et al., 1999b). Again, it seems that Russia and China were the most

Figure 18. Distinct color zoning is evident in this 9.3 mm wide crystal of Russian hydrothermal synthetic bicolored beryl. Photo by John I. Koivula.



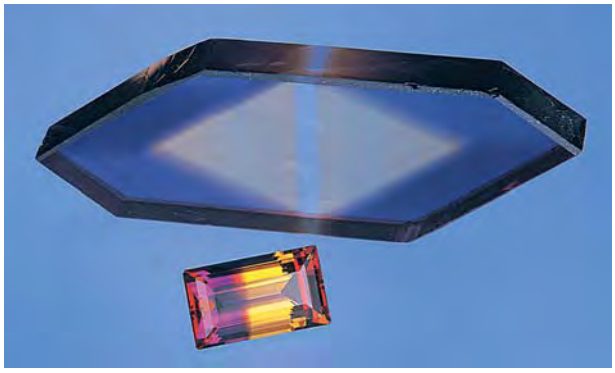
significant participants in researching and producing this material (Landmann, 1999).

There were significant developments in the growth and treatment steps needed to make synthetic **ametrine** (Balitsky et al., 1999a; figure 19), which has been commercially produced hydrothermally from alkaline solutions since 1994. It can be identified by a combination of characteristics, including twinning and color zoning. EDXRF analysis revealed higher concentrations of iron, manganese, potassium, and zinc than have been found in natural ametrine. The infrared spectra of the synthetic citrine portions showed a more intense absorption in the 3700–2500 cm^{-1} range than is seen in the natural counterpart.

Details of the synthesis and identification of Russian hydrothermal synthetic **pink quartz** also were provided by Balitsky et al. (1998; figure 20). Sold under the trade name Flamingo Quartz, this product is grown in autoclaves using an ammonium fluoride solution. As grown, the synthetic quartz is colorless. Phosphorus is the chromophore, and the pink color is produced by a combination of irradiation and heating. Since approximately 200 kg are produced each year, there is a good chance that synthetic pink quartz will be encountered in the trade. When there are no inclusions to aid in detection, the presence of an intense broad band around 3420 cm^{-1} in the IR spectrum provides a useful diagnostic feature.

There is ongoing experimentation with quartz growth techniques that even more closely duplicate nature. In particular, experiments are being done under conditions of high temperature and pressure, using supercritical fluids and trace elements that are typically found in natural quartz (see, e.g., Balitsky et al., 1999b). If synthetics grown under these conditions are marketed commercially as substitutes for natural gems, then the identification criteria on which we currently rely also might change.

Figure 19. Hydrothermal synthetic ametrine was commercially grown for the first time in the 1990s. This crystal weighs 98.55 ct and the cut sample, 7.53 ct. Photo by Maha Tannous.



SYNTHETIC ALEXANDRITE AND CHRYSOBERYL

Czochralski-pulled synthetic alexandrite was marketed in the 1990s under the trade names Nicholas Created Alexandrite and Allexite. Koivula and Kammerling (1991d), Koivula et al. (1992d), and Brown and Kelly (1995) examined a number of Nicholas Created samples and found that some showed a curved internal growth structure. The color change was from a purplish red in incandescent light to greenish blue in day or fluorescent light, with medium to medium-dark tones. While many of the faceted samples examined were virtually flawless, the cabochons usually contained at least a few easily observed gas bubbles, which are useful in their identification. The color change in Allexite is from reddish purple to bluish green (Koivula et al., 1992c). Curved growth features readily identify this material as synthetic, and occasionally minute gas bubbles are seen. Generally, however, Allexite appears flawless at first inspection, which should arouse suspicion.

In the mid-1990s, Russian flux-grown synthetic alexandrite (in twinned and single crystals) was reported by Kammerling et al. (1995e) and

Figure 20. Large amounts of transparent synthetic pink quartz (here, 1.95–16.06 ct) also entered the gem market during the past decade. Manufactured in Russia, this hydrothermal synthetic was sold as Flamingo Quartz. Photo by Maha Tannous.

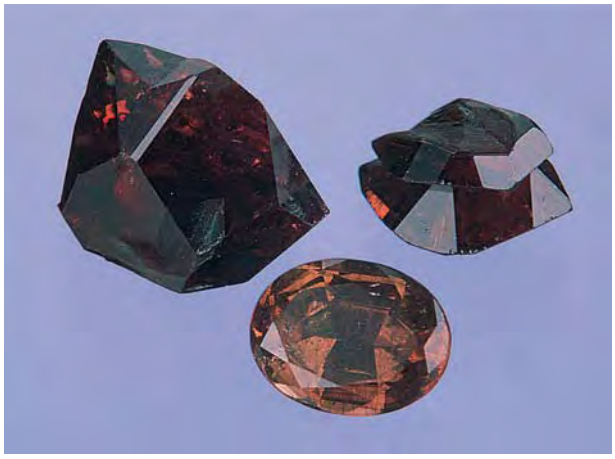


Figure 21. Russian flux-grown synthetic alexandrite, such as these crystals (4.89 and 1.64 ct) and the faceted sample (1.07 ct), appeared on the market in the mid-1990s. Photo (in incandescent light) by Maha Tannous.

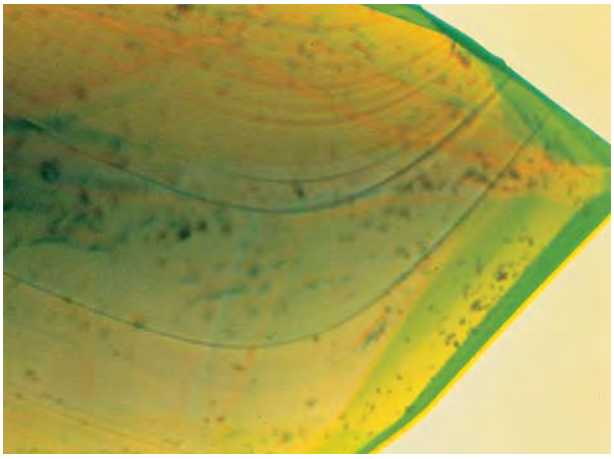


Figure 22. The irregular nature of the curved growth bands is distinctive of the green nonphenomenal synthetic chrysoberyl that entered the market in the mid-'90s. Photomicrograph by Karl Schmetzer; immersion, magnified 60×.

Schmetzer et al. (1996). Using a flux containing molybdenum, germanium, and bismuth, the Russians have produced crystals weighing several carats, from which faceted stones exceeding a carat have been cut (figure 21). Chromium, vanadium, and iron were found to be the chromophores for a color change from brownish red to bluish green. The presence of typical flux inclusions and inclusion patterns makes most samples relatively easy to identify.

Other synthetic chrysoberyls were produced in the 1990s. Johnson and Koivula (1997d) reported on green vanadium-colored synthetic chrysoberyl that had no change of color. This material sometimes contains slightly elongated bubbles and irregular curved growth zones that are best observed with immersion (figure 22). More recently, Krzemnicki and Kiefert (1999) documented bluish green, light green, and pink synthetic chrysoberyl. Vanadium is the coloring agent in the green and bluish green material, while titanium is responsible for the pink color.

SYNTHETIC SPINEL

Although Russian flux-grown synthetic red spinel was first noted by Bank and Henn (1989) and Koivula and Kammerling (1989), it was not until the 1990s that both the red and blue varieties (figure 23) were fully characterized (Bank and Henn, 1990; Brown et al., 1990; Hodgkinson, 1991; Henn and Bank, 1992; Muhlmeister et al., 1993; Johnson and Koivula, 1997b). This research showed that traces of chromium were responsible for the color in the synthetic red spinel and cobalt in the blue, with subordinate iron in both. The flux-grown synthetic blue spinels can be identified by their inclusions, UV fluorescence, and absorption spectrum. If no inclusions are present, the red material requires chemical analysis to determine zinc content, since natural spinel contains significantly more zinc. Synthetic crystals weighing over 10 ct were available.

Figure 23. Although Russian flux-grown synthetic red and blue spinels (here, 0.30–1.23 ct) were introduced in the 1980s, they were not fully characterized until the '90s. Photo by Maha Tannous.

Figure 24. With their color and strong pleochroism, these cobalt-doped synthetic forsterite samples closely resemble tanzanite. The largest cushion mixed cut weighs 6.15 ct. Courtesy of Tom Chatham; photo by Maha Tannous.

In a detailed study of Verneuil (flame-fusion) synthetic spinels, Rinaudo and Trossarelli (1998) noted various patterns of anomalous birefringence when samples were observed in different orientations.

SYNTHETIC FORSTERITE

In 1994, Nassau described synthetic forsterite and synthetic peridot. The chromium-doped synthetic forsterite crystals were grown by the Czochralski method at the Ageo City Central Research Laboratory of the Mitsui Mining and Smelting Co. in Tokyo. A peridot-like color was attained in the rod-shaped crystals, which ranged up to 2.5 cm in diameter and 20 cm long. Not only was this material virtually free of inclusions, but it also showed slightly lower values for specific gravity and refractive indices than those recorded for peridot, due to a low iron content. Johnson and McClure (1999) and Henn (1999b) subsequently described Russian Czochralski-pulled synthetic forsterite with a color and pleochroism (blue and pink; caused by cobalt) that made it an excellent substitute for tanzanite (figure 24). In fact, some of this material has been submitted to the GIA Gem Trade Laboratory for identification. However, the lower refractive indices (1.635–1.671, versus 1.695–1.702 for tanzanite) provide an easy means of separation. Gas bubbles also may be present in this synthetic.

Figure 25. These polished freeforms (3.59–4.30 ct) are typical of Kyocera plastic-impregnated synthetic opals. Photo by Maha Tannous.

SYNTHETIC OPAL

Kyocera of Kyoto, Japan, manufactured and marketed plastic-impregnated synthetic opals in the form of polished irregular nodules in white and a variety of bright colors (Kammerling et al., 1995c). Freeform polished nodules up to about 5 ct were available at the time of that report (see, e.g., figure 25). The bright colors and the unnatural appearance of the play-of-color are an immediate give-away that these opals are not natural. Synthetic orange "fire opal" also was introduced by Kyocera in the 1990s, as a substitute for the natural material from Mexico (Henn and Milisenda, 1999b); infrared spectroscopy revealed the presence of resin as a stabilizer.

Synthetic opals produced in China and Russia were described by Henn et al. (1995). The Chinese material proved to be plastic-impregnated with a corresponding low density. The Russian synthetic opal also had a low density, and some of the black material resembled natural opal that had been sugar- and acid-treated. Both products showed acceptable play-of-color.

In general, synthetic opals are easy to identify unless they are set in a mounting that restricts examination. Depending on how the stone was oriented when it was cut, diagnostic visual characteristics (such as columnar structural patterning) may or may not be visible.

Because of the presence of certain additives, such as plastics used as binding agents, some gemologists and researchers do not necessarily agree that all so-called synthetic opals actually qualify as true synthetics. This is a nomenclature problem that hopefully can be sorted out in the coming decade.

MISCELLANEOUS SYNTHETICS

We continue to see a variety of unusual, if not outright weird, new synthetics that can be fashioned as gemstones. It is unlikely that any of these materials will ever have a large market, or achieve wide acceptance. However, such materials are submitted to gemological laboratories and must be identified accurately. One example is synthetic **sodalite** (figure 26; Koivula et al., 1992b). Experimentally grown in China as heavily included and twinned colorless crystals up to 57 ct at the time of that report, the blue color is due to irradiation.

Recker and Wallrafen (1992) and Henn (1999c) documented synthetic **fresnoite**, a barium titanium silicate grown by the Czochralski method for technical applications. It is reported that crystals of different colors can be grown by the addition of various dopants, but only the yellow-to-orange material is within the color range of the natural mineral. Also, natural fresnoite contains fluid inclusions, which are absent from the Czochralski-pulled synthetics. Only a few very tiny gas bubbles have been observed as inclusions in synthetic fresnoite.

Russian manufacturers have also used Czochralski pulling to grow pink and orange transparent crystals of **yttrium aluminum perovskite** (YAP; Linton, 1997). Like most melt-pulled synthetic crystals, synthetic perovskite can be virtually flawless. This absence of internal features, together with the color (gem-quality perovskite is black, dark brown, or "amber" to dark yellow), should at least warn gemologists that they might be dealing with a synthetic.

Limited quantities of bright blue-green synthetic **phenakite**, flux grown in Russia, also became available in the '90s (Koivula et al., 1994c). The crystals examined were transparent, but contained brownish yellow flux inclusions that would separate them easily from their natural counterpart. These crystals, which weighed up to 12.5 ct, could potentially yield faceted material up to 6 ct.

Another '90s synthetic, which actually became quite popular both as crystal specimens and faceted, was **zincite** from Silesia, Poland (Kammerling and Johnson, 1995). The crystals—some more than 15 cm long—were reported to have formed by vapor deposition as an accidental by-product of an industrial kiln process used to produce zinc-based paint. The faceted samples examined in 1995 (as large as several carats) were yellow, orange, orangy red, and (a very few) yellowish green (see, e.g., figure 27). These synthetic zincites can be readily distinguished by their inclusions, which do not resemble those seen in the natural material, and the fact that they lack manganese.

Figure 26. Irradiation is responsible for the blue color in this 20.38 ct crystal of synthetic sodalite from China. Photo by Robert Weldon.

MISCELLANEOUS SIMULANTS AND IMITATIONS

Amber simulants composed of small chunks and angular fragments of natural resin set in yellow to brownish yellow plastic were available (Kammer-

Figure 27. These synthetic zincites (1.35–3.26 ct) were fashioned from material that was an accidental by-product of an industrial kiln process used to produce zinc-based paint in Silesia, Poland. Photo by Maha Tannous.

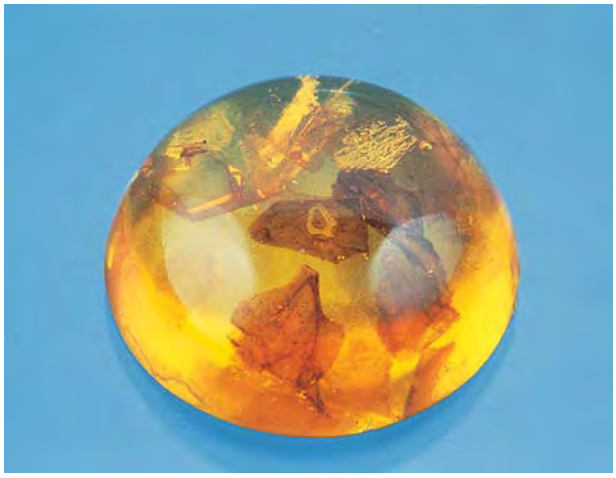


Figure 28. This 8.32 ct amber simulant is composed of plastic with embedded fragments of natural resin. Photo by Maha Tannous.

ling et al., 1995a; figure 28). The material was produced in Gdansk, Poland, and has been described as pressed, reconstructed, reconstituted, or synthetic amber.

An assembled simulant for Madagascar **emerald** consisted of a cabochon of colorless beryl for the dome and a base of heavily included colorless beryl, with a green cement layer between the two (Koivula and Kammerling, 1990a).

Johnson et al. (1999a) reported on a manufactured imitation of **charoite** that was marketed under the name Royal Russianite by Marchant Enterprises of Anchorage, Alaska. The material examined was purple, opaque, and unevenly colored in swirled light and dark tones. A thermal reaction tester produced an acrid odor, as would be expected of a plastic.

A so-called reconstructed **lapis lazuli** was found to consist of barium sulfate with a polymer bonding agent and pyrite inclusions (Kammerling et al., 1991a). Since this imitation does not consist of natural material, *reconstructed lapis lazuli* is a misnomer.

Manning International in New York introduced a composite imitation of **crystal opal** that consisted of synthetic opal fragments in glass (Kammerling and Koivula, 1993; figure 29). Sold under the name Gemulet, the material was offered as faceted stones, small spheres, and tear drop–shaped cabochons.

Although not new to the decade, Majorica imitation **pearls** were ubiquitous on the world market. Hanano et al. (1990) provided a detailed description of the manufacturing process for this very successful pearl imitation, which uses lead-based glass beads coated with "pearl essence," a mixture of guanine extracted from fish scales and binding and coloring agents.

Nontransparent white, pink, and black synthetic cubic zirconia (CZ) manufactured in Russia was marketed in cabochons and beads as substitutes for **pearls**, black **chalcedony**, and black **diamonds** (Kammerling et al., 1991b; figure 30). CZ's high specific gravity compared to the materials for which it substitutes will make items such as long bead necklaces feel relatively heavy. Chalain (1999) provided an update on this material as a black diamond substitute.

Tanzanite imitations entered the market in the 1990s. As reported by Kiefert and Schmidt (1996), some of the most popular tanzanite imitations were a dark violet calcium phosphate glass, a violet flame-fusion synthetic corundum marketed as Blue Coranite, and a purple YAG sold as Purple Coranite. Since none of these imitations has the same gemological properties as natural tanzanite, separation is relatively straightforward. Synthetic forsterite as a tanzanite imitation (again, see figure 24) was discussed above.

Figure 29. "Gemulet" is an opal imitation that is composed of synthetic opal fragments in glass. Photomicrograph by John I. Koivula; magnified 15×.

IMITATION ROUGH

The deceptive alteration or manufacture of gem rough and crystal specimens continued throughout the 1990s. So far, these creations have been rela-

tively easy to detect. However, when dealing with gem rough, just as when purchasing fashioned gems, it's important to know that synthetics and simulants are everywhere: *caveat emptor*—"let the buyer beware."

As expected, **diamonds** were frequently a target mineral for this form of fakery. Cubic zirconia was carved to look like diamond crystals (Crowningshield and Moses, 1996), and topaz was fashioned to resemble diamond rough (Crowningshield and Reinitz, 1997; figure 31). Since topaz has essentially the same specific gravity as diamond, heft provided no indication of the deception.

Imitation **emerald** crystals were the most common form of rough colored stone deception. The materials used ranged from green glass (Koivula and Kammerling, 1990c) to natural quartz fragments held together by a green cement (Koivula and Kammerling, 1990d; figure 32) to quartz coated with green plastic (Johnson and Koivula, 1997a). These manufactured items often would pass a superficial inspection. They usually exhibited a somewhat distorted hexagonal habit, although in one instance a glass imitation displayed only five sides. Typically, they also were "decorated" with at least a little light orangy brown limonitic coating that had small rock fragments and some mica flakes attached. This pseudo-matrix was designed to provide a more realistic appearance.

Ruby and sapphire were also faked. Cobbed as well as tumbled, and otherwise realistically abraded, flame-fusion synthetic rubies were sold as natural rough and preformed rubies from Vietnam (Koivula and Kammerling, 1991c; figure 33). Gemological testing and EDXRF analysis identified these samples as synthetics. Kammerling et al. (1995b) reported on laboratory-grown masses of transparent dark purple GGG seen in Taunggyi, Myanmar, that had been

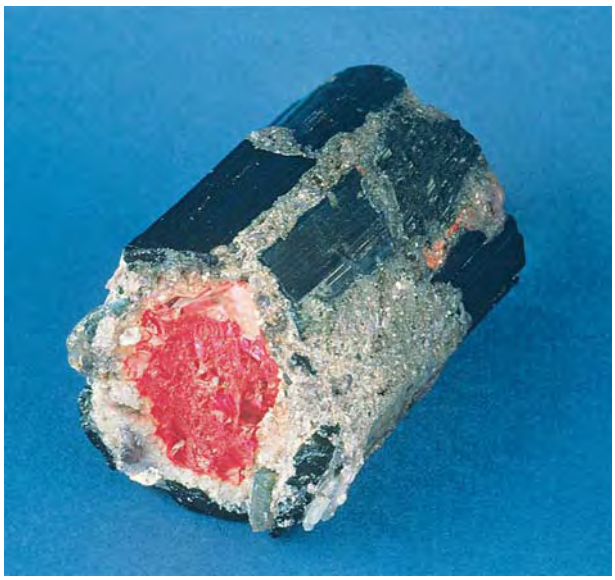
Figure 30. Black, nontransparent cubic zirconia from Russia was used as a black diamond simulant. The faceted sample weighs 6.60 ct. Photo by Shane F. McClure.

Figure 31. Fashioned to imitate diamond rough, these two "crystals" (63.65 and 28.88 ct) were identified as topaz. Photo by Nicholas DelRe.

Figure 32. Purchased in Zambia, these two imitation emerald crystals are composed primarily of quartz fragments that are held together by a green binding agent; the larger sample weighs 63.35 ct. Notice that a dusting of matrix has been applied to provide a more realistic appearance. Photo by Robert Weldon.

Figure 33. All of these pieces of tumbled rough and cobbed material (3.79–15.17 ct) were purchased in Vietnam as ruby, but only the smallest and darkest piece of rough (pictured at the bottom) proved to be natural. All of the others were flame-fusion synthetics that had been fashioned to mimic their natural counterpart. Photo by Shane F. McClure.

Figure 34. This 667 ct imitation watermelon tourmaline crystal is made up of a complex assembly of several materials; only portions of the outermost surface are tourmaline. Photo by Maha Tannous.



fashioned to resemble sapphire crystals and were being sold as coming from a "new locality."

Kane (1991) reported on a "crystal" that had been fashioned from flame-fusion synthetic ruby to look like red beryl. The slightly abraded 23-mm-long hexagonal prism (38.05 ct) contained curved striae and gas bubbles, and showed very strong red UV fluorescence. Because these features are not found in natural red beryl, this simulant was easy to identify.

Probably the most unusual example encountered in the 1990s was an assembled imitation watermelon tourmaline crystal with minor amounts of external "matrix" material (Koivula et al., 1992a; figure 34). This 667 ct specimen consisted of a rock crystal quartz core, a coating of a dark pink coloring agent, and then a layer of mineral fragments in cement. All were contained within long, thin slices of tourmaline on the surface; two of these were dark blue, with the remainder dark yellowish green.

Many other interesting fakes were also documented throughout the '90s (see, e.g., "Fake gems pose threat…" [1999] for examples seen in Africa). Therefore, this section serves only as an introduction to this ongoing problem.

CONCLUSION: LOOKING TO THE FUTURE

What does the future hold for synthetics and simulants? Undoubtedly, technology will continue to advance, and will bring improvements in existing synthesis techniques and the resulting products. Increasing research to produce crystals for high-technology applications should result in a better understanding of crystal growth mechanisms. This will likely result in larger and higher-quality crystals, and the application of growth conditions resembling nature will probably produce more natural-looking synthetics. We should also expect to see a continued (perhaps expanding) variety of laboratory-grown materials (many of which may have no natural counterparts).

The technology of gemstone identification also will move forward. Optics for gemological microscopes will be improved over the next decade so that we will see more, and see more clearly. The detection levels for, and ease of operation of, the advanced instruments that have become increasingly important over the last decade undoubtedly will be improved over the next 10 years.

Will new synthesis processes be developed? Probably. Will the synthetic products grown by them be more difficult to identify? Possibly. What new synthetics will we have to deal with? That's

hard to say. But if we follow existing research trends in the crystal growth industry as they relate to gemology, then we may see a new breed of diamond simulants. Chief among these might be a gem-quality isotropic polytype of synthetic moissanite or the development of other super-hard materials, such as cubic boron nitride, that could have gemological applications as diamond simulants. For colored stones, commercial quantities of synthetic zoisite as a substitute for tanzanite might be realized, as well as chromium-doped synthetic pink topaz. For the most part, however, future developments in synthetics will continue to revolve around the "big four"—diamond, emerald, ruby, and sapphire—since the possibility for profit is highest with these materials. For diamonds in particular, the market for smaller goods is particularly vulnerable to developments in synthetics since testing melee-size stones may be cost prohibitive. More hydrothermal synthetic rubies and sapphires also might appear on the market, as well as more synthetic beryl in different colors.

We also might see a marriage between synthesis processes and gemstone treatment in the form of regrowth and repair of broken natural gemstones. Possible precursors are flux-induced fingerprints in flame-fusion synthetics and experimental hydrothermal synthetic beryl overgrowths on natural beryl seeds.

It is important to remember, however, that we should not focus solely on the products and technologies themselves as we prepare for the challenges of the coming years. When you consider that nearly century-old synthetics and simulants continue to challenge many in the trade, we must also question our preparedness. In this electronic age, while we have advanced our methods of conducting business and have refined our sales techniques to a science, some gem and jewelry professionals still have difficulty identifying even the most rudimentary flame-fusion synthetics, or doubly refractive synthetic moissanite. A sound working knowledge of the identifying characteristics for all synthetics, past and present, is vital. Jewelers and gemologists with these skills will be most ready to tackle future developments in synthetic gem materials.

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Key to abbreviations: *Australian Gemmologist* = *AusG*; *Gems & Gemology* = *G&G* (Gem News = GN, Gem Trade Lab Notes = GTLN); *Journal of Gemmology* = *JofG*; *(Gemmologie:) Zeitschrift der Deutschen Gemmologischen* = *(Gem:) Z. Dt. Gemmol. Ges.*

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TECHNOLOGICAL DEVELOPMENTS IN THE 1990S: THEIR IMPACT ON GEMOLOGY

By Mary L. Johnson

In the last decade, technology has improved how we synthesize, process, identify, and otherwise study gem materials. Significant trends include: the widespread availability of computerized communication; the application of synthesis techniques to gem treatments; the increased prominence of treated synthetics; the greater need for expensive instrumentation to solve gem problems in general, and the broader availability of small dedicated instruments to solve specific problems; and the adaptation of techniques from other sciences. Potentially applicable technology must be evaluated critically to assess its usefulness and appropriateness to solve a particular gemological problem.

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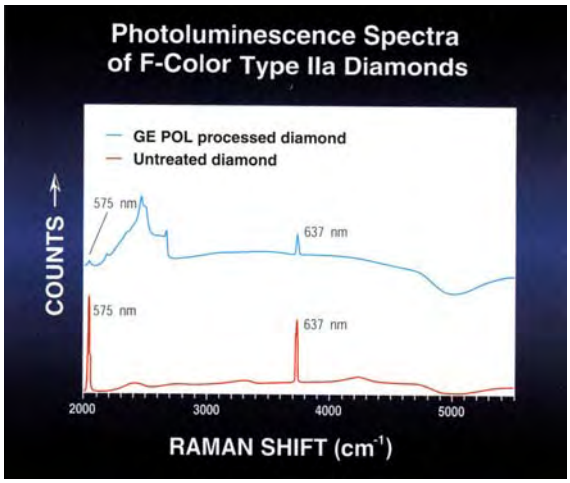
The other articles in this retrospective issue address tangible subjects: localities, synthetic gem materials, treated gems, and jewelry. In contrast, this article is about a concept, *technology*—about *how* we perform tasks differently in the gem trade than we did 10 years ago. A moment's reflection will convince the reader that the changes in the last decade have been enormous, and pervasive. This broad overview is intended to examine the many technological innovations—new methods, new instruments, and new applications for known instruments—that characterized the last decade, and to point the reader to further information. Three trends have been especially important: (1) the rise of computer-related communication; (2) the increasing sophistication of gem treatments, to the point of blurring the boundaries between treatment and synthesis (e.g., high pressure/high temperature–processed diamonds [figure 1] and flux-like fillings and new growth in heat-treated rubies); and (3) the growing need for instrumentation-based identification for gem treatments (e.g., B-jade) and synthetics (e.g., synthetic amethyst). Some widely heralded developments, however, such as the introduction of (doubly refractive) synthetic moissanite as a diamond simulant, reinforce the continued importance of "classical" gemology in this increasingly technological industry.

BACK TO THE BEGINNING: WHERE WERE WE IN 1990?

The Spring 1990 issue of *Gems & Gemology* (Fritsch and Rossman, 1990) described four key challenges from the previous decade that stimulated technological developments in gem testing: (1) the availability of smaller, more powerful computers for instrument control; (2) the introduction of new synthetic gem materials; (3) the advent of new treatments to meet the growing market for colored stones; and (4) the need to produce more and better information about gem materials to

Figure 1. At the end of the 1990s, Raman spectrometry became an important technique for detecting HPHT-processed type IIa diamonds, such as this 0.45 ct E-color GE POL diamond (inset). Photoluminescence spectra (below) obtained with this technique show features—particularly the ratio of the 575 to the 637 nm peak—that can be used to separate the vast majority of HPHT-processed from untreated type IIa diamonds. To achieve high-resolution spectra, the diamonds are cryogenically cooled in a specially designed sample chamber using liquid nitrogen (left). A laser beam is focused through the optical microscope, and a mirror is used to deflect the beam into the sample chamber. Photos by Elizabeth Schrader (inset) and Joe Duffy (left).



meet demand by consumers for better disclosure, especially concerning possibly radioactive gem materials. Greater computer power meant that more data could be processed faster; computer controls also lowered the cost of synthesis by providing better reproducibility and yield. New or improved synthesis techniques included Czochralski pulling, hydrothermal growth, "image furnaces" and skull melting (e.g., for YAG), and HPHT synthesis, especially for diamonds. Chemical vapor deposition (CVD) was used to produce thin-film coatings of (synthetic) diamond and diamond-like carbon; other important treatments of the '80s were irradiation (especially of topaz), fracture filling of diamonds and emeralds, and the treatment of synthetics to resemble treated natural materials.

By 1990, established analytical techniques with gemological applications included: electron microprobe analysis, X-ray fluorescence (XRF) for bulk chemical analyses, infrared and Raman spectroscopy, and cathodoluminescence (especially of diamonds). Other experimentally used detection techniques were: nuclear magnetic resonance (NMR), electron spin resonance (ESR), and proton-induced X-ray emission (PIXE).

Technological changes since 1990 have had an impact on virtually every aspect of the gem business, but most importantly for the gemologist they have affected communication, cut evaluation, development of new gem treatments (and proliferation of synthetics), and growing reliance on more "advanced" techniques. Some of the procedures we use today have been developed within the last decade, but many are refinements of, or adaptations from, earlier technologies. This review does not attempt to achieve completeness, but is intended as a summary of those technological developments that were most important to the gem trade in computers and communication, gemstone cutting, synthesis and treatment, and gem identification (both classical methods and advanced techniques).

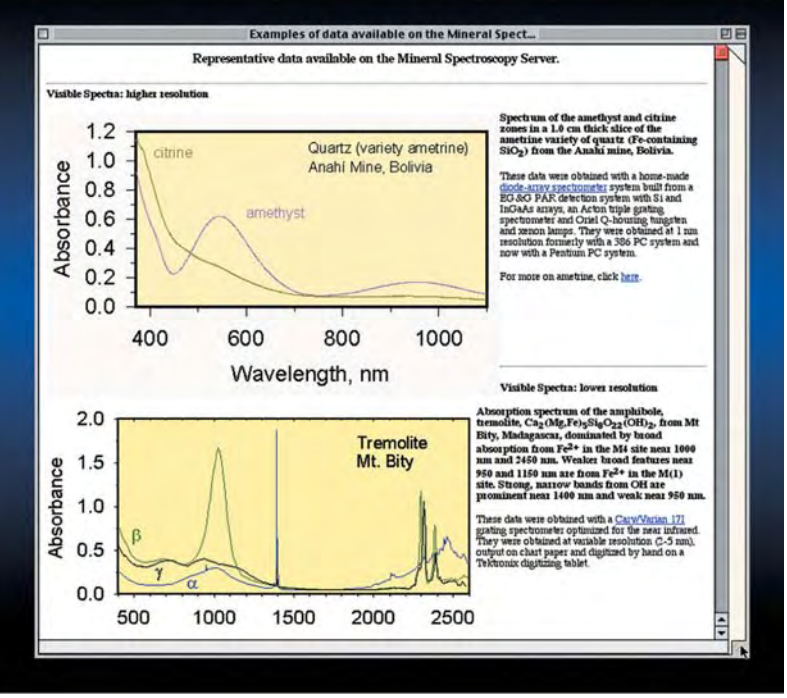


Figure 2. Today, researchers can easily access an abundance of information on the Internet, such as the spectroscopy data on Dr. George Rossman's Mineral Spectroscopy Server at http://minerals.gps.caltech.edu.

COMPUTERS AND WORLDWIDE COMMUNICATION

Perhaps the most significant change in the last decade was the greater reliance on computers and computer networking. The widespread availability of vastly increased computational power and connectivity has revolutionized the way business is conducted, in the gemological laboratories as much as in the rest of the gem trade. For example, both the GIA Gem Trade Laboratory and the AGTA Gemological Testing Center use sophisticated databases to track gem identification and grading data within the laboratory (K. Cino, pers. comm., 1998; K. Scarratt, pers. comm., 2000). Within any business, computers can improve accounting and inventory practices (Golding, 1991), for which commercial software is available (see, e.g., Greig, 1999). The increase in computer power also led to smaller and less-expensive sophisticated instruments; for instance, both Sarasota Instruments (Osprey, Florida) and Adamas Gemological Laboratory (Brookline, Massachusetts) produced PC-based spectrophotometers (Kammerling et al., 1995c; Haske, 1999). P. Read and M. Haske produced new versions of gem identification software (Read, 1996).

Computers also have redefined the expected speed of communications. For example, although *Gems & Gemology* remains a quarterly journal, information on its web site (www.gia.edu/gandg) changes almost weekly. As another instance, on GIA's home page, a forged letter in Thailand was recently disavowed worldwide less than two hours after it first came to GIA's attention (Alex Angelle, pers. comm., 2000). Computers connect a businessperson to an on-line community, with forums for discussion (Voorhees et al., 1999) and specialized commerce sites (business-to-business—B2B—and business-to-consumer—B2C; see, e.g., Diamond, 1999; Weinbach, 2000). Internet retailing is a new development, already going through boom and bust cycles; Janowski (1999) predicted that retailing on the Internet could represent 15% of jewelry business by 2005.

Online archives and databases continue to grow (see, e.g., "The geosciences in review," 1996), making fundamental information available for the price of a few mouse-clicks. A relevant example for the gemological community is Dr. George Rossman's Mineral Spectroscopy Server (http://minerals.gps.caltech.edu; figure 2), which contains an abundance of easily accessible spectroscopy data. Online gemology courses are also available on the Internet. Search engines scan the World Wide Web for relevant information, and "meta-search" engines search the search engines. The new user is cautioned, however, that nonsense on the Internet can be expressed as authoritatively as knowledge is, and that popularity is not a guarantee of quality, so the credibility of the source must always be considered in assessing information.

NEW TECHNOLOGIES IN GEM CUTTING AND CUT EVALUATION

Planning and Cutting Rough. Diamond cutting and polishing (see, e.g., Caspi, 1997) involves many decisions, all meant to maximize the profit achievable from a particular piece of rough. Today, many of these decisions are being made with the help of computerized equipment: These machines can determine which cuts may be fashioned economically ("Sarin's new mapping machine…", 1999); or provide automatic centering, blocking, bruting (figure 3), polishing, and girdle faceting (Hourmouzios, 1996; see also Koivula and Kammerling, 1991d; Lawrence, 1997a, 1998). Laser cutting is another efficient way to fashion rough (Hourmouzios, 1996; Caspi, 1997).

A new theoretical model for the anisotropic behavior of diamond during polishing (that diamond polishes more easily in one direction than another) is based on local conversion of diamond to graphite on the surface during polishing (Van Bouwelen et al., 1997). A new machine, the Horizon 200, has been developed to measure the smoothness of a diamond's surface; results suggest that the more slowly material is removed in the last stages of diamond polishing, the

better the finish quality will be (Lawrence, 1997b).

Software for designing colored stone cuts is available (e.g., Gem Cad [http://www.gemcad.net]; see also Atwell and Hunt, 1993). Automation has also been applied to the fashioning of colored stones. The CSIRO in Australia developed equipment for robotic cutting of opals (Cody and Brown, 1992). In 1994, Golay Buchel demonstrated machine-cut calibrated synthetics and simulants (e.g., synthetic spinel triplets that resemble emeralds) as small as 1 mm in diameter (Koivula et al., 1994a). In 1995, Swarovski debuted machine-cut calibrated colored stones, with a possible production of 300,000 items per day (Kammerling et al., 1995h).

On a related note, many gems respond differently to different types of illumination, and the appearance created by the halogen lamps now generally used in retail jewelry displays is quite different from that seen by the consumer in a more typical at-home or workplace lighting environment. Therefore, Eickhorst (1999) recommended that other types of illumination, such as modern fluorescent lights, might be used to better purpose in selling gems.

Evaluation of Diamond Cut. Although many people "know" that the best cut for a round brilliant diamond was determined by Marcel Tolkowsky in 1919, research on proportions and cut began before then and has continued to the present day (see, e.g., references cited by Hemphill et al., 1998). All such models rely on assumptions about the source of illumination (spectrum, location, size, and shape) and the position of the diamond relative to the observer (e.g., Love, 1989, assumed that a diamond is more brilliant if it looks brilliant while tilted as well as face-up). Some modern analyses rely on computers to predict the optical performance of various cuts and sets of proportions (see, e.g., Hemphill et al., 1998; Gilbertson, 1999; http://www.gemology.ru); but geometric models continued to be produced, mainly in the Japanese literature (see, e.g., Kato, 1991). At this time, there is no consensus as to the "best" set of proportions for round brilliant cut diamonds.

NEW TECHNOLOGIES IN SYNTHESIS AND TREATMENT

Innovations in synthesis and treatment, and the application of existing technologies to new starting materials, led to a variety of new gem materials in the 1990s. Because there are articles in this issue that address synthetics and treatments in depth (Koivula et al., 2000; McClure and Smith, 2000), the discussion here will focus on synthesis and treatment technology rather than identification.

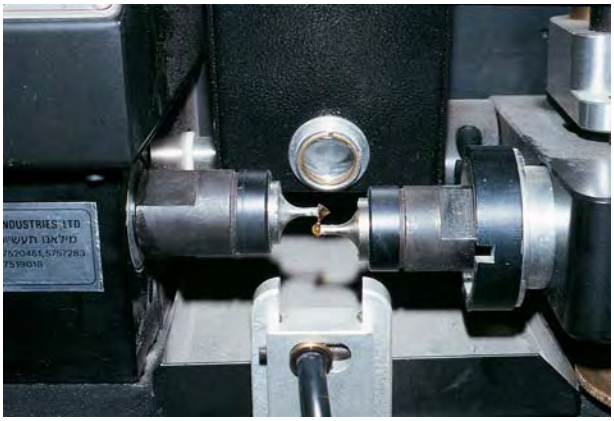


Figure 3. Automatic bruting machines were one of the many innovations in planning and cutting diamond rough in the 1990s. Photo by James E. Shigley.

Colored Stone Synthesis. As discussed in the "Synthetics" article in this issue (Koivula et al., 2000), Russia and China were important centers of gem synthesis during the decade (see, e.g., Schmetzer, 1990; Bukin, 1992; Thomas et al., 1997; Johnson and Koivula, 1998e; Tauson et al., 1998; Balitsky et al., 1998, 1999a,b; and synthetic diamond references cited below). At the VNIISIMS facility near Moscow in 1994, about 500 researchers were investigating synthetic gem materials, using equipment such as the furnaces shown in figure 4 (Koivula et al., 1994c).

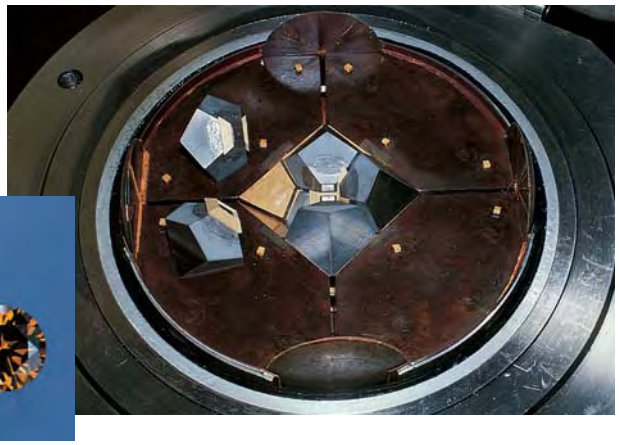
Anhydrous (without water) crystal growth techniques described include pulled-melt growth techniques for synthetic forsterite (Nassau, 1994); top-seeded solution growth and pulling from a melt with a continuously varied composition (applied to fluorides, but adaptable to other synthesis challenges; Koivula et al., 1992c); flux growth of synthetic alexandrite (Schmetzer et al., 1996) and synthetic spinel (Bukin, 1992); and growth of gem-quality synthetic moissanite by the Lely sublimation process (Nassau et al., 1997). Czochralski-pulled synthetic corundums made from naturally occurring starting materials were represented incorrectly as "recrystallized" rubies or sapphires (Kammerling et al., 1995g). Flux-grown synthetic emerald crystals grew larger if phosphorus was added to the flux (Kayama and Kuwano, 1998), or if grown from oriented seeds in a rotating crucible (Barilo et al., 1999). A study of yttrium-aluminum oxide melts explained why large YAG crystals cannot be grown from a flux: The melt separates into two viscous fluids that do not recombine

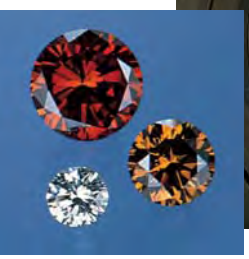
Figure 4. Although not new technology, furnaces such as these in Chernogolovka, Russia, were used to grow large quantities of synthetic gems in the 1990s. Photo by James E. Shigley.

easily (Aasland and McMillian, 1994). Growth zones in hydrothermal synthetics may be due (at least in part) to sporadic temperature fluctuations during the growth process (Thomas et al., 1999).

Diamond Synthesis. Throughout the 1990s, HPHT diamond synthesis employed a variety of large presses (see, e.g., figure 5). These included a belt-type apparatus (a piston/cylinder press with a special, strengthened central cylinder); multiple-anvil presses with tetrahedral, octahedral (Koivula and Kammerling, 1991b), or cubic symmetry; and split-sphere presses (sometimes called BARS for the Russian initials: see, e.g., Koivula et al., 1992d; Shigley et al., 1993b). Most HPHT synthetic diamonds are grown in a nickel-iron flux (see, e.g., Burns et al., 1999; Choudhary and Bellare, 2000); high-quality synthetic diamonds, with fewer defects than natural diamonds, can be grown using a temperature gradient in the HPHT cell (Pal'yanov et al., 1998). Efforts have been made to grow diamonds from graphite-carbonate (Akaishi et al., 1990), -hydroxide, -sulfate, -phosphate and -borate fluxes (Kanda and Akaishi, 1991), as well as from a silicate (kimberlite) flux (Arima et al., 1993), but so far the resulting crystals have been very small. However, as many of the characteristic features of synthetic diamonds—e.g., magnetism, types of inclusions, and luminescence spectra—are a result of the fluxes used, the development of alternative fluxes must be watched carefully.

Figure 5. This BARS apparatus in Novosibirsk is typical of the split-sphere presses commonly used to manufacture Russian synthetic diamonds, such as the 0.04–1.07 ct samples in the inset. Shown here is the sample chamber as viewed from directly above. Photo of press by James E. Shigley; examples in inset courtesy of Alex Grizenko, photo by Maha Tannous.





Gem Treatments. Heat treatment of rubies and yellow and blue sapphires was performed in high-temperature furnaces (figure 6) with carefully controlled atmospheres; methods used during this decade were described in detail by Themelis (1992) and Emmett and Douthit (1993), with additional details gleanable from Themelis (1995) and Johnson et al. (1999a). Wang et al. (1992) used molten salt baths, at somewhat lower temperatures (900°C rather than 1200°–1800°C or so), to improve the color of blue sapphires. Diffusion treatment, which introduces chromophores at and near the surface of fashioned corundum, was described by Kane et al. (1990). As the decade progressed, the depth of possible diffusion treatment increased, and in some samples the need for repolishing was eliminated, minimizing the characteristic color concentrations at facet junctions (Emmett, 1999).

The most contentious emerald treatment was clarity enhancement (fissure filling); controversies raged as to whether disclosure rules should be different for emeralds that had been "oiled" than for those so treated with artificial resins such as Opticon and the new Gematrat and Permasafe treatments. Work by Zecchini and Maitrallet (1998) and Hänni and colleagues (see, e.g., Hänni et al., 1996a,b; Chalain et al., 1998) indicated that artificial resins and commonly used "essential oils" had different infrared and Raman spectra. However, using the same instrumentation on a greater number of known and potential fillers, Johnson et al. (1999c) showed that artificial

resins could not be distinguished from such oils with 100% certainty. Emerald treatment equipment (figure 7) became available in the early 1990s from several sources, including Israel (e.g., Koivula et al., 1993a; Koivula et al., 1994b).

Instances of stones rendered radioactive by treatment continue to be discovered. In the last decade, americium was used to irradiate diamonds (Ashbaugh and Moses, 1993; Reinitz and Johnson, 1994), some of which will be radioactive for thousands of years. Reactor-irradiated (and radioactive) ruby (Johnson and Koivula, 1998d) and cat's-eye chrysoberyl (to make "chocolate-brown" body color; Johnson and Koivula, 1997d) were discovered in circulation; in some cases, these could be quite hazardous.

Toward the end of the decade, new identification challenges emerged on two fronts: (1) the distinction of treated synthetics from synthetics, and (2) the use of synthesis methods to treat natural gem materials. Synthetics are treated for several reasons: to achieve colors not otherwise available (e.g., red treated-color synthetic diamonds: Moses et al., 1993), to disguise the synthetic nature of the starting material (e.g., quench-crackled or diffusion-treated synthetic corundum: Johnson and Koivula, 1997b, 1998b; Free et al., 1999), or to "stabilize" low-quality starting material (e.g., polymer-impregnated synthetic opal: Johnson and Koivula, 1998c). Some laboratories, such as the GIA Gem Trade Laboratory, now disclose certain treated synthetics on identification reports (e.g., treated-color synthetic diamonds, diffusion-treated synthetic corundum, and polymer-impregnated synthetic opal: Shane McClure, pers. comm., 2000).

In the past, synthesis methods applied to treatment have entailed creating overgrowths on existing gems (such as CVD overgrowths on diamonds and Lechleitner synthetic emerald overgrowths on beryl), and such techniques continue to be used. However, even techniques thought to be used simply for treatment can create new growth; for instance, Mong Hsu rubies show new crystal growth with heat treatment (Johnson and McClure, 2000). High-temperature techniques that can be used for both synthesis and treatment blur the line between treated gems and synthetics.

One of the most important recent developments in diamond treatments is the use of high pressure and high temperature for short amounts of time to either decolorize the diamond or give it a more attractive color. This treatment works by changing the aggregation state of nitrogen in the diamonds, introducing or modifying defects, and possibly changing the degree of strain (see, e.g., Smith et al., 2000, pp. 194–195). Synthetic diamonds have been "annealed" (70–80 kbar pressure and 2000°–2200°C for 4–5 hours) to produce yellow and greenish yellow hues (Shigley et al., 1993a). Fancy yellow synthetic diamonds with type IaA aggregates can be produced by treating typical (type Ib) synthetic yellow diamonds at high pressure (Koivula et al., 1992d). HPHT processing of some brownish type IIa natural diamonds can remove color to the point of rendering the stone colorless (D–F); early experiments with this method were done in Russia (Teslenko, 1993), and recently General Electric has been processing diamonds in this fashion for commercial distribution (for further information on these GE POL diamonds, see, e.g., Johnson et al., 1999b; Moses et al., 1999).

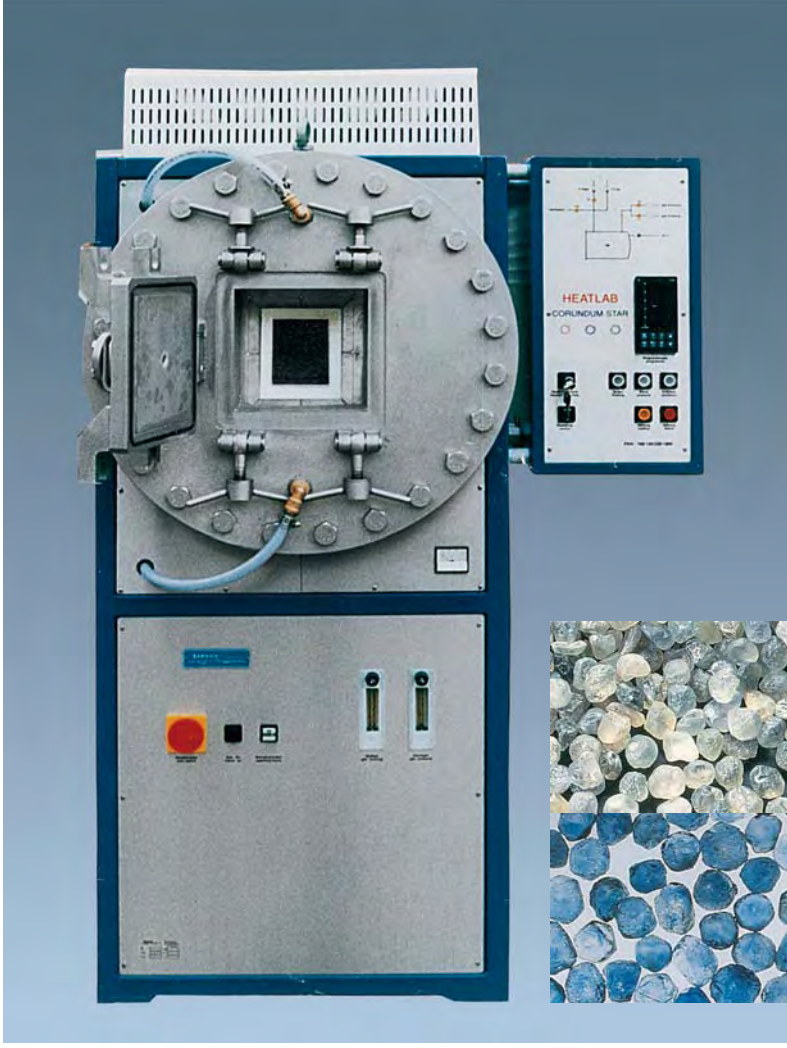


Figure 6. High-temperature furnaces such as this one were used with carefully controlled gas mixtures to perform heat treatment of rubies and yellow and blue sapphires (see inset for stones before [top] and after treatment; average size 4.5 mm). Furnace photo courtesy of Linn High Therm GmbH; inset photos © GIA and Tino Hammid (top) and © John L. Emmett (bottom).

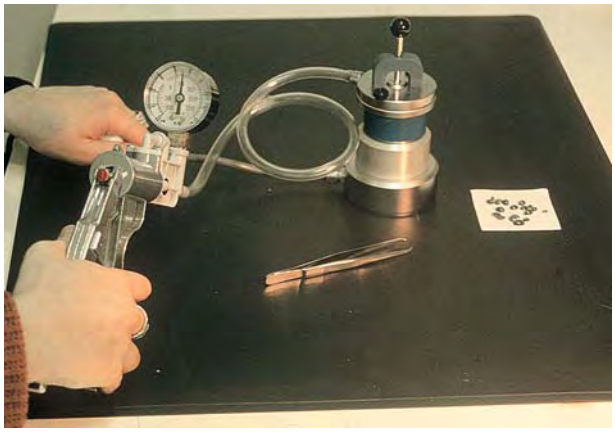


Figure 7. In the early 1990s, emerald treatment equipment became available from several sources. The "Mini Oiler" shown here uses a hand-operated vacuum-pressure pump both to remove air and moisture from fractures and to create pressure for fracture filling. Photo courtesy of Colgem-Zamrot.

Other brown type Ia diamonds turn greenish yellow to brownish yellow (Henn and Milisenda, 1999; Reinitz et al., 2000—see figure 8). For a review of related technology, as revealed in recent patents for HPHT treatment, see Schmetzer (1999).

NEW TECHNOLOGIES IN GEM IDENTIFICATION

Gemological Techniques. "Classical" gemology is a relatively mature field; consequently, technical gains in this area over the last decade have for the most part been small refinements and discoveries, not major innovations. Among these were:

- Refinement of weight estimation formulas for mounted stones (Carmona, 1998a,b)
- A procedure to measure the specific gravity of mounted goods (Mitchell, 1992)
- Alan Hodgkinson's "visual optics," including a method to distinguish diamond from various substitutes by noting the pattern of dispersed flashes from a fashioned stone (Hodgkinson, 1989), as well as tests with simple equipment to estimate or determine optic character, birefringence, dispersion, pleochroism, and refractive index (Hodgkinson, 1995)
- Confirmation of appropriate tests to identify black opaque gem materials (Johnson et al., 1996), including examining the surface in polarized reflected light
- Use of polarized reflected light to help identify opaque inclusions at the surface of non-opaque gems (Crowningshield and Johnson, 1994)
- An explanation of the "Plato effect" in synthetic corundum (Johnson and Koivula, 1999), which is seen by looking edge-on at the irregular edges of mosaic crystallites
- Use of microscopic techniques from optical mineralogy by gemologists to identify small particles, such as minute scrapings from a gem (Hodgkinson, 1994)
- Obtaining the optic figure of a transparent inclusion in a transparent gemstone, using a "conoscope" (focusing lens on a microscope) in contact with the host gem (Koivula, 1993)
- Use of short-wave UV radiation to distinguish striae in synthetic sapphires (Kammerling et al., 1994)
- Use of pleochroism to tell diffusion treatment (pleochroism should exist) from coating (no pleochroism) for anisotropic gems (Koivula and Kammerling, 1991a)
- Use of a refractometer to measure dispersion, by calibrating results against benitoite and fluorite (Hanneman, 1992)
- Use of thermal conductivity to distinguish (most) synthetic emeralds from (most) natural emeralds—synthetics tend to have lower values (Read, 1990a)

Gemological Instruments. Innovations also continued in the development and improvement of instruments for basic gemology. The following are a few of the many advances in the decade. Reflectivity meters, including the Brewster-angle refractometer, compensate for their lower precision than standard refractometers by measuring a wider range of refractive indices (up to 3.3: Read, 1990b; Kammerling et al., 1995a). Dr. W. Hanneman produced many small gemological instruments, including an inexpensive replacement for a quartz wedge, which could be used with a microscope to determine the optic sign of a gem (Koivula et al., 1992b). Because darkfield illumination is generally needed to see small inclusions well, a darkfield loupe was developed by GIA GEM Instruments (Koivula and Kammerling, 1991c; figure 9).

Other new gemological equipment included two types of immersion cells to distinguish diffusion-treated corundum, one illuminated (Koivula et al., 1992a; Linton et al., 1994) and one for use with a penlight (Read, 1993). A modified "phosphoroscope" for short-wave UV testing was described by Elen and Fritsch (1999, pp. 36–37). A strong magnet on a convenient mounting could be used to distinguish (most) unmounted synthetic diamonds that

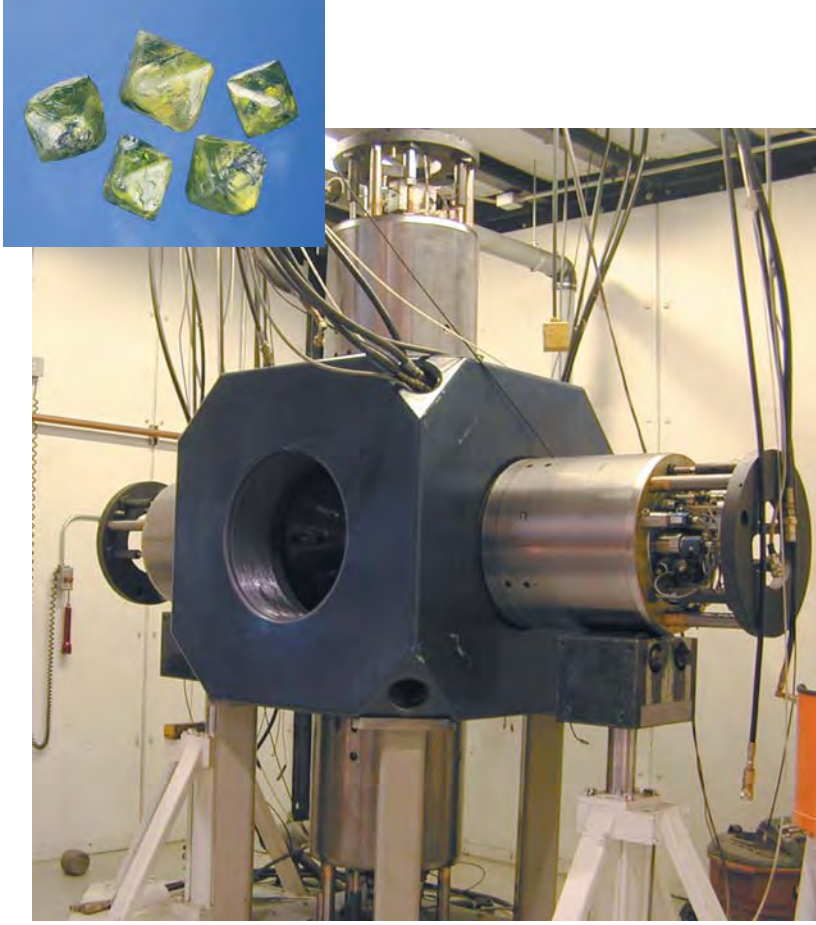


Figure 8. With presses such as this one, diamonds are exposed to high pressure and high temperature for short periods of time to give them a more attractive color. These five greenish yellow HPHT-treated diamond crystals (1.90–4.45 ct) were originally brown. Instrument photo courtesy of Novatek; inset by E. Schrader.

contain metallic inclusions from natural diamonds (Kammerling et al., 1995d; Hanneman, 1996; Hodgkinson, 1996). H. Linton and colleagues on the Gemmological Association of Australia Instrument Evaluation Committee reviewed many new gemological instruments in the *Australian Gemmologist*, including: the Bailey light source, an inexpensive, low-powered replacement for sodium D-line illumination for a refractometer (Linton et al., 1996); and the Meiji Technico GF-252 combination refractometer/polariscope (Linton et al., 1997).

Growth Structure Analysis. Although morphological crystallography—the study of a material by identifying its crystal faces and their relationships—predates the discovery of X-rays, during the 1990s a variation of this approach was developed to gain information about the internal structure of gem materials. Faces (and corresponding growth zones) are most easily identified by their shapes, but these shapes can change with relative size; a better technique is to use the angles between adjacent growth zones, which do not vary. Kiefert and Schmetzer (1991a,b,c) used a horizontal immersion microscope to measure these angles, and showed valuable applications (e.g., distinguishing Nigerian and Colombian emeralds from synthetic emeralds). Perhaps the simplest example of this technique is the identification of synthetic diamonds on the basis of cubic growth zones (not present in natural diamonds, which grow as octahedra; Welbourn et al., 1996 [figure 10]). Growth features also are useful to understand the growth histories of some rubies (see, e.g., Peretti et al., 1995; Smith, 1996) and blue sapphires (Schwarz et al., 1996).

Color Measurement. Color comparison requires color standards, a choice of illumination (see, e.g., Yonick, 1999), a consistent (nondistracting) background, and trained color graders with proven excellent color perception (Brown, 1993; King et al., 1994). During the 1990s, machines were devised to measure color, especially for D-to-Z diamonds (e.g., Gran and Austron colorimeters; Shor, 1999). In a new application of old technology, existing measurement equipment, such as multichannel spectroscopy, was used to "grade" colored diamonds; however, these devices were of limited effectiveness due to differences in viewing geometry (compared to visual grading), the effect of gemstone fluorescence, and some reproducibility concerns (Peretti, 1995). Color can be communicated via computer by, for instance, collecting gemstone image spectra (Wagner, 1999); however, all such methods are accurate only if the sending and receiving devices are properly calibrated and can detect and show the correct colors (which depends on the color "gamut" of each piece of equipment).

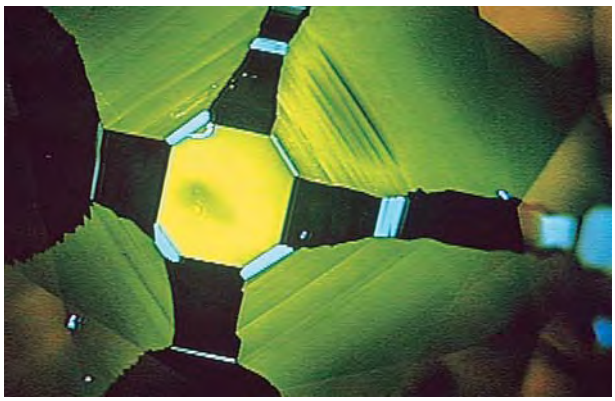
"Black Boxes." A "black box" in this context is a relatively small piece of equipment that gives a choice of simple responses; it is not necessary to understand the technology to use such a device, although understanding prevents many interpretation errors (see, e.g., Liddicoat, 1996). The most common "black boxes" are diamond testers, to distinguish diamonds from (most) simulants. A new generation of these were introduced, from hardness pencils to UV-transparency meters, with the commercial development of synthetic moissanite as a diamond simulant (see, e.g., Nassau et al., 1997; Hammer and Stefan, 1999; Hanneman, 1999), because synthetic moissanite reads as diamondon most traditional diamond testers. The De Beers DiamondSure distinguishes synthetic diamonds

Figure 9. The darkfield loupe, shown here with a flashlight and tweezers, was developed by GIA GEM Instruments to help gemologists see small inclusions.

from most natural diamonds on the basis of the presence (in most natural diamonds) of the 415 nm optical absorption line (which is absent in synthetic diamonds), as described by Welbourn et al. (1996; see figure 11). Although this device was not commercially available at the end of the decade, it was in use in some major gemological laboratories.

Another important set of "black boxes" consists of measuring devices. Like a Leveridge gauge, the Presidium Electronic Gemstone Gauge measures the external dimensions of a gemstone (Linton and Brown, 1990). The Presidium DiaMeter-System Berger (again, see Linton and Brown, 1990), Sarin BrilliantEye (Lawrence, 1998), and OGI Megascope ("New machine . . . ," 1998) measure the proportions of fashioned stones, mainly diamonds, and provide "cut grades" according to predetermined criteria (often a choice of proportion ranges for "Ideal" cuts). According to its manufacturers, the GemEx BrillianceScope Analyzer quantifies "dispersion," "light return," and "brightness" (Schoeckert and Wagner, 1999), although no reviews of this equipment were available by the decade's end.

Figure 10. The yellow-fluorescing octagon in the middle of the table of this 2.19 ct synthetic diamond represents growth on a cubic face. Cubic growth zones are not seen in natural diamonds. Photo courtesy of De Beers DTC Research Centre.



INNOVATIONS IN ADVANCED ANALYTICAL TECHNIQUES

Of increasing importance in gemology is the need to have recourse to techniques that require more sophisticated (and more expensive) instrumentation. Commonly referred to as "advanced testing," these techniques were developed for—and used routinely in—other sciences, especially chemistry, physics, and geology (see, e.g., Hawthorne, 1993). They usually require considerable training both to use the instruments and to interpret the results. Applications of some specific techniques to gemology are described below.

Improvements and New Vistas for Established Techniques. Although techniques such as infrared and Raman spectroscopy were developed long before the 1990s, they became far more important to gemological laboratories during this decade. Such techniques were also modified or adapted to answer new challenges presented by treatments and synthetics.

Ultraviolet-Visible (UV-Vis) Spectroscopy. This was a mature technology, with a few new developments in the 1990s. Diamond spectra are generally run at low temperatures to improve resolution, but Lifante et al. (1990) noted that by taking mathematical derivatives of room-temperature spectra—that is, by examining the changes of slope in these spectra—better resolution could also be achieved. Diffuse UV-Vis reflectance spectroscopy can be used in combination with infrared techniques to identify gems, and a database of these spectra has been produced (Tretyakova et al., 1997, 1999).

Infrared Spectroscopy. During the 1990s, IR spectroscopy found some important new applications. This is the best technique to determine whether or not jadeite has been bleached and polymer-impregnated (Fritsch et al., 1992; figure 12), and IR analysis of jadeite has now become standard practice in some gemological laboratories. Smith (1995) showed that the IR spectra of heat-treated Mong Hsu

rubies were different from those of unheated rubies. Emeralds fall into five different groups based on IR spectra in the hydroxyl and water regions, although water-rich samples require emerald powder to be mixed into KBr pellets, which is somewhat destructive (Schmetzer and Kiefert, 1990). Most manufactured glasses can be distinguished from obsidian and other natural glasses based on their IR spectra (Owens, 1999). Yan et al. (1995) described an infrared microscope that works in much the same way as a Raman microspectrometer: Visible-light optics are used to focus on the region of interest, and an IR spectrum is then collected.

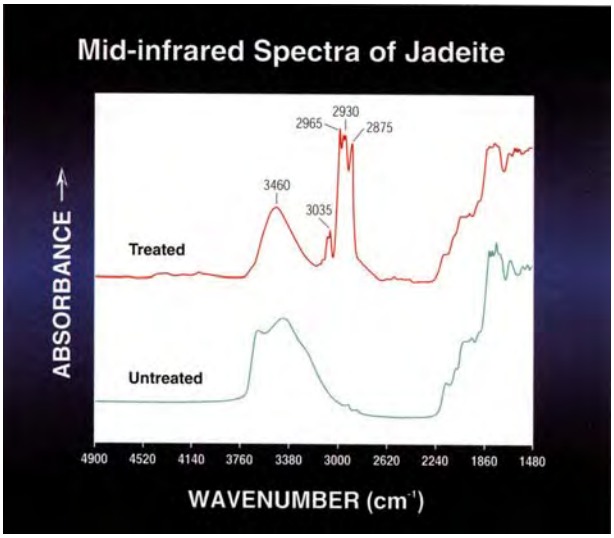
Diamonds are usually divided into four types (Ia, Ib, IIa, and IIb) based on the amounts of trace nitrogen and boron present, and the aggregation state of the nitrogen, as evident in their IR spectra (Fritsch and Scarratt, 1992; Weldon, 1999). Knowledge of diamond type can help separate natural from synthetic diamonds (see, e.g., Shigley et al., 1995); also, different diamond types react differently to HPHT processing.

Although transmission geometry (i.e., the beam is passed through the sample) is used in most gemological applications, IR spectroscopy is also useful in reflected beam mode. With the latter, the beam may be bounced off the sample's surface or focused within the sample (e.g., Johnson et al., 1999c). Although this technique is sometimes called DRIFT (diffuse reflected infrared Fourier transform) spectroscopy, for gemological purposes the beam generally is transmitted through the sample and then reflected off a mirror, rather than being reflected off the sample surface. Reflectance IR spectroscopy has been used to detect fillers in emerald (see, e.g., Zecchini and Maitrallet, 1998; Chalain et al., 1998) and jadeite (Quek and Tan, 1997), as well as to distinguish synthetic from natural emeralds (Johnson and Koivula, 1996a). Tretyakova et al. (1997) noted that three reflected-radiation techniques (reflected IR, reflected UV-visible spectroscopy, and reflected Raman) have their individual limitations, but can be used together to derive more complete results.

Raman Spectroscopy. Perhaps the single most important "new" instrument in gemological research in the last decade was the laser Raman microspectrometer (again, see figure 1). This sensitive luminescence technology found widespread use in the nondestructive identification of inclusions (and fillers) in various gem materials, even under the gem's surface, as well as of the gem materials themselves (see, e.g., Koivula et al., 1993b; Hänni et al., 1997; Johnson and Koivula, 1997c). Because Raman spectra can be gathered on mounted gems, this is a convenient technique for examining artifacts (see, e.g., Hänni et al., 1998). Toward the end of the decade, it promised to play a key role in the identification of HPHT treatment in diamonds.

Figure 11. Based on the absence or presence of the 415 nm absorption line, De Beers's DiamondSure refers synthetic diamonds and some natural diamonds for further testing while "passing" most natural diamonds. The fiber-optic probe is mounted vertically (as here) for testing loose stones, and can be removed for testing mounted stones. Photo by M. J. Crowder.

Figure 12. IR spectroscopy has now become standard practice in some gemological laboratories for determining whether jadeite has been bleached and polymer-impregnated. The strong absorption in the 2900 cm^{-1} region of the mid-infrared spectrum is particularly useful for detecting treated jadeite.



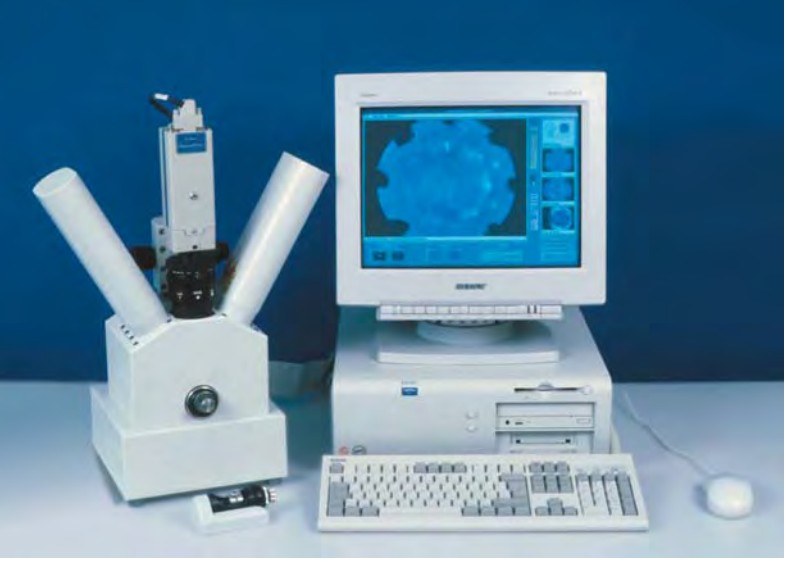


Figure 13. The De Beers DiamondView images a diamond's fluorescence to radiation below 230 nm in wavelength. The blue fluorescence of the natural diamond shown on the monitor is typical of most natural diamonds. Photo courtesy of De Beers DTC Research Centre.

This technique provides a "fingerprint" of the material tested: Raman spectral peaks of crystalline substances are sharp and occur at fixed energies; less-organized materials such as opal, resins, and oils have broad but often distinctive spectral features. Today, most major gemological laboratories have a Raman microprobe (microspectrophotometer).

Spectral libraries were needed to apply Raman analysis easily to gemology; one of the first in this field was produced by Pinet et al. (Schubnel, 1992), while others are available from manufacturers (e.g., Renishaw) and on the Internet (e.g., http://minerals.gps.caltech.edu/files/raman). Given a reliable spectral library, a Raman spectrum can provide within minutes an identification that otherwise might require several hours for both chemical analysis and X-ray diffraction.

Some gem materials luminesce to the laser excitation, and this photoluminescence can swamp the Raman signal (Kammerling et al., 1995f), or itself be captured and evaluated. Luminescence spectra have been collected at room temperature (Chalain et al., 1999) and low temperatures (Fisher and Spits, 2000; Smith et al., 2000; again, see figure 1) from diamonds suspected of HPHT treatment, in the hope of developing robust identification criteria. At the turn of the millennium, this is an active area of significant research.

Luminescence Spectrometry and Imaging. This topic includes luminescence to UV radiation (fluorescence) and to visible light (photoluminescence; see discussion of "Raman spectroscopy," above), as well as time-delayed emission of light (phosphorescence). A prototype "microspectrofluorimeter" was developed to collect emission spectra from small spots on samples (Dubois-Fournier et al., 1989); it is also possible to see photoluminescence by placing a sample between two filters that together block out all light (the "crossed-filter" technique: Hoover and Theisen, 1993). The De Beers DiamondView (Welbourn et al., 1996) images samples using their fluorescence to radiation below 230 nm in wavelength (i.e., at higher energy than short-wave UV). At these energies, all diamonds fluoresce, and synthetic diamonds show different patterns of growth than natural diamonds (figure 13).

Many studies in the '90s used cathodoluminescence, collecting images and spectra from samples that glow on exposure to an electron beam (see, e.g., Ponahlo, 1989; Johnson and Koivula, 1998a). Sunagawa et al. (1998) used cathodoluminescence images to confirm that two faceted diamonds came from the same piece of rough. Pulsed cathodoluminescence has yielded new spectral features in corundum and spinel (Solomonov et al., 1994).

Electron Microprobe Analysis and Scanning Electron Microscopy. Again, these technologies should be considered mature (even in gemology), and were routinely used for chemical analysis and imaging of gem materials during the decade (see, e.g., Raber, 1996). Two types of detection systems are employed for chemical analysis: (1) energy-dispersive spectroscopy, which is quicker; and (2) wavelength-dispersive spectroscopy, which is much more accurate (Nikischer, 1999). "Windowless" detectors and layered crystal detectors (both of which became more common in the 1990s) have made it possible to measure the light elements boron, carbon, oxygen, nitrogen, and fluorine (see, e.g., Hänni et al., 1994; Johnson and McClure, 2000). SEM detectors became so efficient that it was possible to show the opal structure in Kyocera impregnated synthetic opals without first carbon- or gold-coating the samples (Kammerling et al., 1995b).

X-ray Fluorescence Spectroscopy and X-ray Diffraction. XRF was applied routinely to many identification problems in this decade. This technique is used to get an approximate bulk chemistry of various materials, including colored stones, diamonds (e.g., to detect fracture filling), and pearls (to distinguish freshwater from saltwater pearls and to detect some treat-

ments). There have been a few new applications in this decade. For instance, since the penetration depth of the X-ray beam can be less than the sample thickness, XRF has been used to demonstrate diffusion treatment in a star sapphire (Johnson and Koivula, 1996b). Energy-dispersive (EDXRF) systems with element-mapping capability now permit researchers to observe the distribution and concentration of chemical components within a sample (e.g., the Kevex Omicron: Sam Muhlmeister, pers. comm., 2000).

X-ray diffraction is another "mature" field, with few relevant innovations to applied gemology (versus, e.g., characterization of new gem species) in the last decade. One notable development is the availability of diffraction reference spectra on CD-ROM, with computer search capability (from the International Center for Diffraction Data, Newtown Square, PA).

Metals Testing. In one way, metals are easier to test than gems, as the use of destructive testing is usually less of a concern. Four metal-testing techniques—density, chemical reactivity, capacitative decay, and chemistry by EDXRF—were reviewed by Mercer (1992) and found to be insufficiently accurate to meet U.S. legal standards. However, five years later, nondestructive "X-ray assay" was considered reliable enough to substitute for fire assays for testing metals (Reilley, 1997). LA-ICP-MS (laser ablation–inductively coupled plasma–mass spectrometry; see below) is more precise, allowing gold samples to be tracked from specific mines by their trace-element contents ("'Fingerprinting'…," 1995; see also Guerra et al., 1999). Particle accelerator–based techniques such as PIXE (see, e.g., Demortier, 1989) are even more precise, but access to such machines is limited, and they have been used mainly on archeological artifacts (e.g., Calligaro et al., 1998; Demortier et al., 1999).

Promising Newcomers: Academic Techniques Being Adapted to Gemology. *Isotopic Studies and ICP-MS.* These tests are innately destructive, on one scale or another: Conventional isotope studies require that the elements being studied be ionized as a liquid or gas, while microbeam techniques use a laser or ion beam to blast ionized particles from small (i.e., tens of microns in diameter) spots in the sample (see, e.g., Günther and Kane, 1999). The resulting trace-element and isotopic data can yield extensive information about gems, such as clues to formation ages and parent material. Ion probes and LA-ICP-MS can measure light elements such as hydrogen, lithium, and beryllium in gems ("The geosciences in review," 1996), providing a practical micro-equivalent to wet chemistry as well as isotope chemistry. However, the (micro) destructive nature of these techniques, as well as their limited availability and expense, will likely restrict their gemological applications in the near future. In addition, as the spot size (and resulting crater) gets smaller, reproducibility may suffer.

There have been several isotopic studies of emeralds, especially by Giuliani and co-workers (see, e.g., Cheilletz et al., 1994; Giuliani et al., 1997, 1998, 2000). The oxygen isotopes of Colombian, Afghan, Brazilian, Zambian, Tanzanian, and Nigerian emeralds may be related to their source rocks and temperatures of formation (Johnson and Koivula, 1997a; Giuliani et al., 1998), which may provide clues to the locality of origin.

Conventional ICP-MS has been used to distinguish elephant from mammoth ivory, based on strontium-to-calcium ratios (Sato et al., 1991). Together with Fourier transform infrared (FTIR) spectroscopy and optical techniques, Pulz et al. (1998) used ICP-MS to distinguish Campos Verdes (Goiás, Brazil) emeralds from those from Colombia, Swat (Pakistan), Itabira (Minas Gerais, Brazil), and Franqueira (Spain).

X-ray Imaging Techniques. X-ray topography—creating images from diffracted X-rays—was described by Sunagawa et al. (1998), who used it (with cathodoluminescence) to determine that two fashioned diamonds had been cut from the same piece of rough. Synchrotron Laue patterns of rough Argyle diamonds have shown that they are more likely than diamonds from other sources to contain slightly misoriented crystallites; because of this mosaicism, Argyle diamonds have a high wear resistance for industrial uses, but are harder to polish as gems (Clackson and Moore, 1992). Coatings, as well as mosaic crystals, can be imaged using X-ray diffraction tomography (Liangguang et al., 1999).

Other Physical and Chemical Techniques. Various other instrumental methods have been applied to the analysis of gem materials through cooperative programs at universities and other institutions, which make otherwise prohibitively costly, experimental, and/or restricted equipment available to researchers. Using computer-aided tomography (CAT scanning), a pearl was shown to be attached to the shell in which it had grown (Wentzell, 1995). Scanning tunneling microscopy (STM) is one of a family of related micro-surface techniques that have many applications in computer-chip testing but are

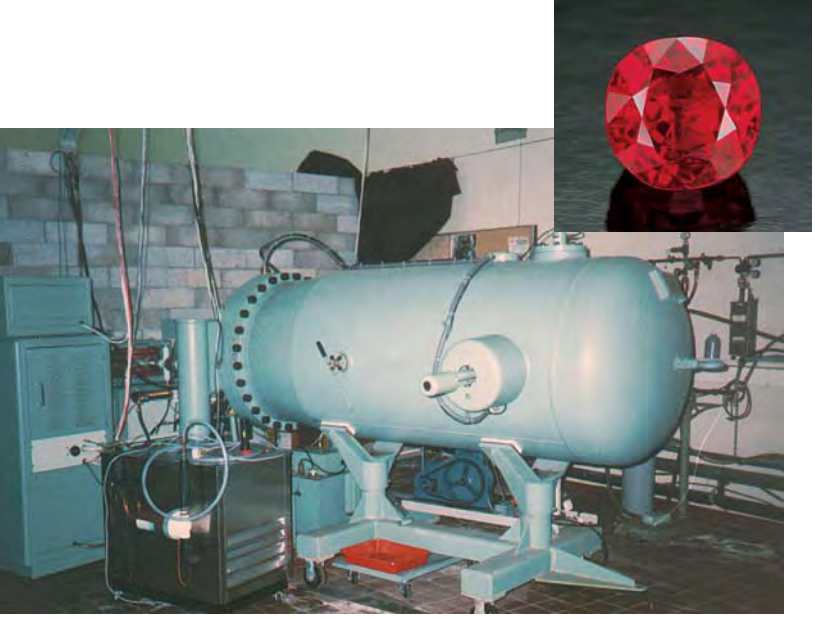


Figure 14. Proton-induced X-ray emission (PIXE) analysis has been used to nondestructively measure the trace-element concentrations in gems and metals. The Van de Graaff accelerator shown here is one method used to generate the proton beam for this technique; photo courtesy of Tay Thye Sun. Several PIXE studies have been performed on rubies (see inset of Burmese stone; courtesy of Amba Gem Corp., photo © Tino Hammid).

only beginning to be applied to the study of gems. STM revealed that diamond polishing proceeds by chipping in the hardest directions, and by plastic deformation and subsequent graphitization in other directions (Van Enckevort et al., 1993; Van Bouwelen and Van Enckevort, 1999). PIXE analysis (figure 14), an ion-beam technique, has been used for the nondestructive measurement of trace-element concentrations in gems and metals in Egyptian jewelry (Koivula et al., 1993b; Querré et al., 1996), as well as in rubies from Myanmar and Thailand (see, e.g., Kammerling et al., 1995e; Sanchez et al., 1997), and diamond inclusions (Ryan and Griffin, 1993). X-ray photoelectron spectroscopy (XPS), an analytical technique for surfaces, can determine elemental compositions and oxidation states, and gives similar results to FTIR in testing for surface waxing or polymer impregnation in jadeite (Tan et al., 1995).

Nuclear magnetic resonance (NMR), a nondestructive technique that probes the local environment of specific elements such as hydrogen and fluorine, can separate some natural and synthetic emeralds, and may be able to detect heat treatment in aquamarines (again, see Koivula et al., 1993b); it also shows promise for being able to separate synthetic from natural pink-to-orange sapphires (Troup et al., 1992). Electron paramagnetic resonance (EPR; also called electron spin resonance, or ESR—see, e.g., Hutton and Troup, 1994b) has been used to investigate the valence state and bonding properties of certain transition elements in gems, including: manganese in pink tourmaline (Petrov, 1990), vanadium in emeralds and green beryls (Hutton and Troup, 1994a), chromium in natural and synthetic alexandrites (Rager et al., 1998), and nickel in annealed synthetic diamonds (Mashkovtsev et al., 1999). Laser tomography has been used to image small defects in heat-treated sapphires (Shida, 1990) and synthetic rubies (Koivula et al., 1993b). At this time, these techniques are more academic than practical, but each of them could make useful gemological determinations.

Statistical Analysis. The estimation of errors is important in the assessment of the validity of any experimental study, regardless of the technique used. Recently, however, "demographic" studies have been introduced, which use (often simplified) statistical techniques to study the properties of data populations, rather than individual samples or observations. For example, the diamond fluorescence research of Moses et al. (1997) was mainly a statistical study of human perception of diamond color and transparency as a function of intensity of blue fluorescence. Although individual responses were quite variable, and sometimes even contradictory, overall trends in appearance aspects could be discerned. This study was unusual for gemology in that it considered general population trends, instead of individual responses and observations of individual items.

SUMMARY: INNOVATIVE TRENDS IN THE 1990s AND SOME PREDICTIONS

In their 1980s review, Fritsch and Rossman (1990) suggested the following as significant remaining challenges for the gem trade: determining natural versus treated colors in natural gems (especially green diamonds, blue topaz, and red tourmaline), instrumentational determination of heat treatment (especially corundum) and dyes (e.g., "lavender" jade), and the reproducible measurement of a gem's color. Progress has been made on some of these issues in the last decade—notably on determining the origin of color of green diamonds, perhaps the most economically important of these issues—but no definitive methods or solutions have yet been published, and newer crises have relegated the rest of these issues to a much lower priority.

This last decade was one in which technology brought changes to nearly every aspect of gemology

and gem manufacturing. To this author, the following trends best summarize the current need for, and spirit of, innovation:

- *The Internet is for everybody.* Widespread availability of information (of all levels of quality) means that sophisticated consumers may know more—or think they know more—about gems than their retailers do.
- *Computers calculate proportions and cut designs.* To the degree that a gemstone's optical performance can be modeled accurately, cuts can be planned and optimized without wasteful trials. Verification is still required, however.
- *Robots fashion gems.* Used at first for calibrated goods, robotic cutting creates relatively uniform results.
- *Lighting concerns are increasingly important in the retail store and the laboratory.* The optimal lighting environments for viewing gems for purchase as well as gemological evaluation will likely be a major research focus over the next decade.
- *The use of high temperatures and synthesis methods for treatment has begun to blur the line between treated gems and synthetics.* The classic 1990s examples were the (very) high temperature heat treatment of Mong Hsu rubies, which grows new material, and the use of high pressure/high temperature both to produce synthetic diamonds and to decolorize or otherwise improve the color of natural diamonds.
- *However, treated synthetics are now considered a category in their own right.* The GIA Gem Trade Laboratory, for example, currently identifies diffusion-treated synthetic corundum and polymer-impregnated synthetic opal.
- *"Black boxes" provide specific solutions to certain gemological problems.* In some cases, as with synthetic moissanite testers (used to distinguish diamond from a doubly refractive substitute), these devices may substitute for a lack of basic gemological skills, or the time needed to practice them.
- *More treatments and synthetics require advanced testing.* For example, a piece of jadeite may show no obvious signs of polymer impregnation when viewed with a microscope, but this treatment may be readily apparent when the sample is examined with FTIR.
- *Statistical studies and computer databases may lead to "profiling" of gem materials by expert systems.* We have now reached the point where computers are better able than individuals to keep and compare relevant observations; in the future, these systems should be able to spot goods representing new mines, synthetics, and treatments.
- *New and old techniques from other sciences continue to be adapted to solve gemological problems.* Mineralogy, chemistry, and physics have been fruitful sources of advanced techniques with gemological applications, but other sciences (such as biology) may provide more techniques in the future.

It is difficult to know which of the many technologies reviewed in this article will make the greatest impact in the future. Most of the technical innovations that affect the trade today have their roots in the technologies of previous decades. The most significant development has been in the rate at which changes reach us. We have less time to react than we did in the past: Crises come on top of crises, challenges on every scale hit at once. Continuous education is therefore a key to success.

Although it is true that gem identification is becoming increasingly difficult (a trend that will certainly persist), often requiring sophisticated laboratory instrumentation and techniques, it is also true that the competent gemologist can still ascertain a tremendous amount of information using classical gem-testing methods that are routinely available. By staying on top of the gemological literature, and applying this newly gained knowledge to classical gem-testing methods, competent gemologists can accurately identify many gem materials and, as importantly, determine when they need to submit a gem to an independent, recognized laboratory.

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Key to abbreviations: *Australian Gemmologist* = *AusG*; *Diamond and Related Materials* = *DRM*; *Diamond International* = *DI*; *Gems & Gemology* = *G&G* (Gem News = GN, Gem Trade Lab Notes = GTLN); *Industrial Diamond Review* = *IDR*; *Journal of Crystal Growth* = *JCG*; *Journal of Gemmology* = *JofG*; *Journal of the Gemmological Society of Japan* = *JGSJ*; *Nuclear Instruments and Methods in Physics Research B* = *NIMB*; *Revue de Gemmologie* = *Rev. de Gem.*; *(Gemmologie:) Zeitschrift der Deutschen Gemmologischen Gesellschaft* = *(Gem:) Z. Dt. Gemmol. Ges.*

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JEWELRY OF THE 1990S

By Elise B. Misiorowski

This article provides an overview of the many changes that took place in how jewelry was designed, manufactured, and marketed during the last decade. Driven by a highly competitive market that favored the unique, designers created innovative cuts for diamonds and colored stones. The use of gem materials in the '90s was marked by a greater demand for fancy-color diamonds, colored stones in dramatic combinations, and large and multicolored cultured pearls. In precious metals, the emphasis shifted toward platinum and other white metals. Designer jewelry took on a variety of distinctive setting styles, textures, and motifs. As designers sought to distinguish themselves through name recognition, the branding of diamonds and finished jewelry became a major force. Jewelry worn by entertainers and promoted in the mass media touched off instant trends, which the new marketplace of television shopping networks and the Internet was able to accommodate directly.

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For the jewelry world, the decade of the '90s was an eclectic one, filled with strong contrasts and balanced opposites. Jewelry design expanded in every direction, with the wide variety of motifs ranging from ancient or ethnic (figure 1) to ultramodern. There was a Renaissance in cutting styles for both diamonds and colored gems, and pearls reached new heights of popularity.

The economic ups and downs in the '90s had a profound effect on the jewelry world. Japan, the strongest market for jewelry as the decade opened, went into an economic recession in the early '90s, setting off a domino effect on the economies of Korea, Thailand, and the rest of Southeast Asia. Although there was a slump in consumer spending in those areas, it was offset by the new buying power of China and a stronger jewelry market in the United States and Europe. Surveys indicated that the typical jewelry buyers of the '90s in the U.S. were young married women with full-time employment and no children, older women whose futures are secure, and teenagers (*Precious & Fashion Jewelry Markets*, 1997), while a study by the World Gold Council indicated that women are the primary jewelry buyers in Europe as well ("Market place...," 1997). Fine jewelry became less formal, as it became an important part of the working woman's wardrobe. More women wore pearls or diamonds with with blue jeans and tennis dresses, integrating fine jewelry into every aspect of their lives.

At the same time, the discovery and mining of new gem deposits, as discussed in the "Localities" article elsewhere in this issue (Shigley et al., 2000), made many gems more available. New cuts for both colored stones and diamonds were introduced, revitalizing jewelry design. In addition, jewelry competitions proliferated, further stimulating design and shifting the direction of jewelry styles, while promotion of jewelry through the media—both print and film—stimulated consumer demand. With strong competition in the marketplace for jewelry and gems, jewelers and gem dealers began promoting their particular "brand," and branding became a strong and increasingly important trend in the '90s. The potential power of the Internet as a marketing tool for jewelry also became evident, and auction hous-

Figure 1. Designers in the '90s drew inspiration from many sources and interpreted it in a contemporary manner. This group of jewelry designed by Carolyn Tyler combines faceted citrines and black pearls set in granulated 22K gold in Renaissance-style cruciform motifs, the pendant suspended from a pearl and gem bead torsade necklace. Courtesy of Stones of Fire, Bali.

es played a greater role in the marketing of contemporary as well as estate jewelry.

All of these developments—and more—contributed to a decade that saw both subtle advances and dramatic innovations in the use of gem materials, as well as in the design and marketing of jewelry. As space is limited, this overview will focus on capturing the essence of trends in fine gemstone jewelry (excluding watches) as seen in the U.S. market rather than attempt to address every nuance of change in the international jewelry world. Similarly, as it is impossible to credit every important jewelry designer of the decade here, the emphasis will be on those who made significant advances in jewelry design or gem cutting, or whose work exemplified specific trends during this period.

DIAMONDS

Trends. There were several new twists in the diamond market. Advertising and promotion of diamonds created a more enlightened and interested consumer so that, in areas where the economy was strong—Japan in the early '90s and the U.S. later in the decade—there was a new demand for quality. The '90s buyer was interested in diamonds that were not only of high color and clarity, but were cut to good proportions as well. As a result, a number of dealers began to promote as a name brand standard-cut diamonds that guaranteed quality. Lazare Kaplan International set the trend with the Lazare Diamond, which was cut to "Tolkowsky Ideal" proportions ("Designer diamonds...," 1997). Other companies swiftly followed suit, and brand-name diamonds became a hot new trend. "Branded" diamonds fell into four specific categories: well-fashioned standard cuts, such as the Lazare Diamond; new varieties of fancy cuts, such as the Quadrillion and the Criss Cut; treated diamonds, such as those that were Yehuda fracture-filled; and diamonds from specific sources (often with distinctive colors), such as Argyle pink and "champagne" diamonds. Several companies also developed lines of jewelry designed around their branded diamonds, further increasing their market exposure (Federman, 1997).

Not only was there a strong market for standard- and fancy-cut diamonds, but interest also developed in antique cuts such as the briolette, rondelle, old European, and rose. Even early table and portrait cuts, which date from the 16th and 17th centuries, made a showing, as did diamond beads, which are without historic precedent but have an old-fashioned look (Federman, 2000). Briolettes gained popularity as pendants and earring drops, rondelles were used as spacers in important pearl and gem bead necklaces, and diamond beads were offered in dazzling single strands or mixed with other gem beads in necklaces and bracelets (figure 2). Rose, old European, table, and portrait cuts were incorporated into antique-style jewelry as well as into some ultramodern styles. Even the natural beauty of rough diamonds was appreciated, as octahedral, dodecahedral, and cube-shaped diamond rough was set in jewelry during this highly unusual decade.

Without listing every diamond cut brand, it is important to mention some of the new shapes and facet arrangements developed during the 1990s, as many of these provided the impetus for innovative

Figure 2. Various "old" diamond cuts became newly fashionable during the 1990s; these included the old European and briolette cuts seen in the elongated drop earrings (inset). Exquisitely understated when worn as a single strand, diamond beads also add importance as spacers in a fine pearl necklace. Courtesy of Michael Goldstein, New York.

Figure 3. In the face-up position, it is impossible to see the gold grid that holds the diamonds from beneath in this pendant, which has been invisibly set with Quadrillion diamonds that have been customized to fit the heart-shaped outline. Courtesy of Ambar Inc., Los Angeles.

jewelry design. Developed in the 1980s, square brilliant cuts for diamonds, known as Princess cuts, and rectangular brilliants grew in popularity during the '90s. Much of this popularity was due to the fact that rectilinear brilliant cuts made it possible—for the first time—to invisibly set diamonds. In the late 1930s, when invisible settings were first introduced, the technique was used only with rubies, sapphires, and emeralds. At that time, rectilinear diamonds were step cut and the metal grid used to hold the gems from beneath was easily visible through them. Square brilliant diamonds, however, break up the light so that it is impossible to see the metal that holds the stones. Invisibly set diamonds became a strong stylistic feature of '90s jewelry by such companies as Ambar Diamonds, who patented their square brilliant cut as the Quadrillion ("Square cut brilliance," 1994; (figure 3)). The fact that square and rectangular brilliant cuts also concentrate color in diamonds may have contributed to the popularity of these cuts as interest in fancy-color diamonds increased.

In addition, the four-lobed Lily cut (by Eternity Diamond Corp.) and the five-pointed Star cut (by Fancoldi) are two unusual shapes developed during this period, while the Context and Spirit Sun cuts, designed by Bernd Munsteiner, were radical departures from standard cuts. The Context cut is polished as a perfect octahedron to emulate one of diamond's natural crystal habits. The Spirit Sun consists of a series of triangular facets radiating from center culets on both crown and pavilion to imitate the sun's rays (figure 4; Federman, 1997).

Melee and calibré-cut diamonds continued to be popular throughout the '90s in pavé and channel settings. This may have been driven by the fact that cutting operations in Israel stepped up their production of precision-cut, calibré goods, while India and Thailand produced large quantities of small, inexpensive diamonds ("Thailand," 1991; Even-Zohar, 1997). In counterpoint to this, demand for larger diamonds increased as the decade progressed. The stock market boom in the U.S. during the late '90s, along with the success of many Internet companies, brought sudden wealth to a surprising number of business entrepreneurs. As a way to demonstrate their new affluence, these entrepreneurs began to acquire large, fine-quality diamonds of 5 ct and above (Shor, 1998).

Fancy-Color Diamonds. Traditionally considered rare and exceptional, fancy-color diamonds became

Figure 4. Bernd Munsteiner's "Spirit Sun," set here in a swirl ring by Michael Good, was one of the radical new cuts for diamond developed in the '90s. Courtesy of Michael Good, Rockport, Maine.

more prominent in the 1990s. This was primarily due to the greater availability of fancy brown, yellow, and pink diamonds from Australia's prolific Argyle mine and the promotional program launched to sell them. The marketing blitz for these stones inspired greater interest in all fancy-color diamonds, which were frequently featured in designer jewelry. Because Argyle's colored diamonds are typically small, they are primarily suited for pavé work, which stimulated a trend for colored diamond pavé jewelry. Even black diamonds, previously considered primarily for industrial use, were cut and pavé set with colorless diamonds and other gems to dramatic effect (Federman, 1999a). Fawaz Gruosi of de Grisogono was one of the earliest to use black diamonds in jewelry. He came out with a striking line in 1997 that incorporated pavé black and colorless diamonds in areas of strong contrast. The trend was soon adopted by a few other designers, including Michelle Ong, who interpreted it in her own style (figure 5).

There was also increased demand for larger fancy-color diamonds. Although yellow, brown, and pink were again the colors most frequently seen in sizes over a carat (figure 6), diamonds of blue, red, violet, orange, and green hues, in various tones and saturations, found ready buyers among connoisseurs and collectors (Bogel and Nurick, 1997; Heebner, 2000). In response to this demand for colored diamonds and their greater availability, GIA fine-tuned its color grading system for fancy-color diamonds in the mid-1990s (King et al., 1994). This period also saw the greater use of irradiated diamonds, which brought colored diamonds to a wider clientele.

Figure 5. Black diamonds became fashionable in the late '90s, especially pavé set with colorless diamonds in strongly contrasting "black and white" jewelry such as this lyric leaf brooch in platinum by designer Michelle Ong for Carnet, Hong Kong. Note also the use of briolette diamonds. Photo © Tino Hammid.

Figure 6. Still a rare and pricey commodity, fancy-color diamonds were frequently set as the focal point in rings. This ring, designed by Beat Schönhaus of Geneva, is set with a 1.55 ct pink marquise diamond accented by yellow diamond melee and colorless baguettes in a platinum and 18K gold mounting. Courtesy of Fancoldi; photo © Tino Hammid.

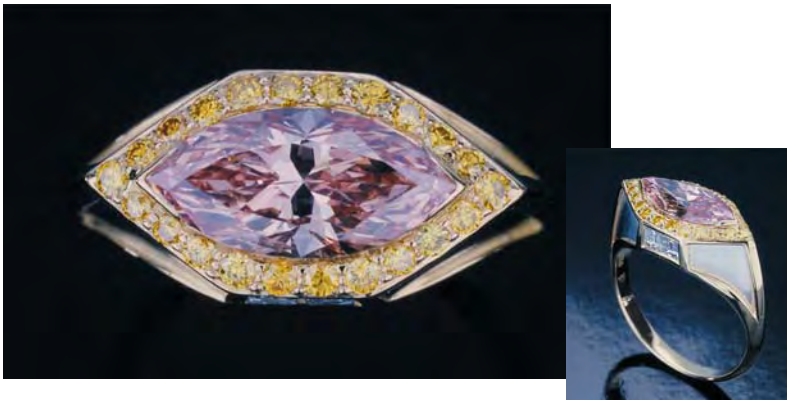

Figure 7. Rich combinations of vividly colored gems were one of the biggest trends during the '90s, as seen in this 18K gold necklace set with tourmaline, tanzanite, and purple garnet. The use of granulation and woven wire in high-karat gold was another prevalent trend. Courtesy of Kent Raible.

COLORED GEMSTONES

Trends. Rubies and emeralds had the strongest market share early in the decade but suffered credibility setbacks toward the end, when highly charged treatment controversies were aired on television and blazoned in the press (see, e.g., Bergman, 1998). As concerns heightened about treatment in emeralds and rubies (see the "Localities" and "Treatments" articles elsewhere in this issue), other colored gems gained prominence. Strong favorites were tanzanite and tsavorite, rhodolite, and Mandarin garnets from Africa, while fancy-color sapphires from Sri Lanka, Africa, and (later in the decade) Madagascar grew in popularity. Deep blue, "electric" blue, and "neon"-green tourmalines from Brazil's Paraíba mines were instant winners, while more red and bright pink spinels from Myanmar appeared on the market. Opals of every sort from Australia continued to be steady sellers.

Colored gems were featured as the focal point in jewelry surrounded by diamonds, or they appeared with other gems of saturated hues. Typical were rich and unusual combinations such as red spinel with orange spessartine garnet, purple amethyst with deep red rhodolite, green tsavorite with violet-blue tanzanite, "golden" yellow sapphire with blue sapphire, Imperial green jade with ruby, blue sapphire with hot pink spinel, green tourmaline with rhodolite garnet, orange citrine with brown or green zircon, and black onyx with iridescent mother-of-pearl or any of the above gems (figure 7).

In contrast to these vivid combos, lighter-toned, less intensely colored gems were also in vogue. Understated, but hardly aloof, the pastel hues of aquamarine, green beryl, rose quartz, "golden" as well as pink and lavender sapphires, light green and pink tourmalines, morganite, kunzite, iolite, and translucent blue chalcedony gained a fresh presence in jewelry of the '90s (Kremkow, 1999).

Fascination with phenomenal gems also intensified. At the high end of the market, there were ready buyers for star ruby and sapphire, cat's-eye chrysoberyl, alexandrite, and cat's-eye alexandrite, while gem cognoscenti and collectors snapped up color-change sapphire and garnet. Moonstone, adularescent transparent labradorite (also known as rainbow moonstone), and virtually every variety of opal appeared in a wide range of jewelry as cabochons, beads and—for opal especially—as carvings and inlay (Dang, 1998; DePasque, 1999—figure 8).

Ornamental opaque and translucent gem materials such as lapis lazuli, black chalcedony, chrysoprase, turquoise, sugilite, malachite, and azurite-malachite were all brought into play as accent stones, in beads, or as inlay. Jade, a traditional favorite throughout Asia, gained new appreciation in the West. Imperial green jadeite commanded astonishing prices at auction: At the November 3,

Figure 8. The use of various gems as inlay was very popular during the '90s. Opal inlay is used here in a particularly attractive combination with tanzanites and channel-set diamonds. Courtesy of Kabana, Albuquerque, New Mexico.

1999, Christie's sale in Hong Kong, for example, a cabochon ring sold for US$2,405,000, while a bangle sold for US$2,576,000. Both set new world records for these types of Imperial jadeite jewelry ("Jadeite jewellery," 1999). Lavender jade and translucent white jade also increased dramatically in demand and value (Christie's, 1999), whereas nephrite jade in green, yellow, orange, rust, and black was commonly used in jewelry during the 1990s.

Even gem varieties previously thought of strictly as collectors' gems appeared in jewelry during the 1990s. These include blue-green apatite (misnamed "Paraíba" apatite in the trade because of its color similarity to the green tourmalines from Paraíba, Brazil), "golden" brown sphene, bright red rhodochrosite, and royal blue haüyne (see, e.g., Knox and Lees, 1997; Kiefert and Hänni, 2000). Although generally considered too soft or friable for most jewelry uses, these gems have strong color and show to great advantage in earrings, necklaces, or brooches, where they are not as susceptible to damage during wear.

Cuts and Cutting. There was much experimentation with gem cutting in the '90s, and designers—hungry for ways to stand out in the highly competitive market—immediately incorporated new and unusual cuts into eye-catching jewelry. Fantasy cuts, introduced by Bernd Munsteiner in the 1980s ("The father of fantasy," 1991), evolved in wonderful ways in the hands of many additional artists. Michael Dyber added concave circular facets, called Dyber Optic Dishes, to flat facets in fantasy-cut transparent gemstones (figure 9). These concave facets reflect throughout the stone, like bubbles or planets orbiting in a galaxy (Weldon, 1994). Another innovation was Bart Curren's Fantasy Interlocks, matching pairs of fantasy-cut stones in contrasting gem materials that fit together like pieces of a puzzle.

Fantasy cuts became more expansive in the hands of such lapidary artists as Glenn Lehrer and Steve Walters, who created wide, undulating carvings that rippled and coiled like waves or smoke (figure 10). Fashioned predominantly from black onyx, lapis, chrysoprase, and other chalcedonies, these carvings were a breakthrough style of the '90s. Artists created another compelling effect by retaining some of the gem's natural polycrystalline (drusy) surface (figure 11). Glenn Lehrer also developed round disc shapes with a hole cut in the center, similar to a piece of Lifesavers candy. Applied to both transparent and translucent gems, his Torus Ring GemCut echoes the ancient Chinese "Pi," symbol of eternity.

Figure 9. Fantasy cuts grew in popularity during the '90s. Michael Dyber won first place in the 1994 AGTA Spectrum awards with this 262.70 ct Bolivian ametrine on which his carved Dyber Optic Dishes show to great advantage. The ametrine carving has been set as a pendant by goldsmith Paul Gross. Courtesy of Michael M. Dyber, Rumney, New Hampshire; photo by Robert Weldon.

By rewarding innovation and excellence in the cutting of colored gems, the Cutting Edge competition (sponsored by the American Gem Trade Association [AGTA]) inspired gem cutters to devise new concepts. Outstanding among the many superb designer cuts are the concave facet cuts developed by Richard Homer, for which a special machine, the OMF Faceter, was developed (Homer, 1990). The integration of concave facets into a standard brilliant cut gives his finished gems a fluid, lacy appearance (Dick, 1990a; Taylor, 2000). Other innovative cuts that became more popular in the '90s included cushion or saddle shapes with step-cut facets covering their domed crowns in a checkerboard pattern, or in a single row similar to louver-blinds. Known

Figure 10. The sinuous curves of this fantasy-cut black onyx look like rippling water or coiling smoke. Carved by Steve Walters, this approximately 5 cm long piece is set as a brooch designed by C. Y. Sheng. Photo by Maha Tannous.

respectively as the "checker" and the "opposed bar" cuts (Vargas, 1975), they appeared primarily in rings or as graduated suites in necklaces. Drop-shaped briolette cuts also became highly fashionable for both transparent and translucent colored stones, particularly in earrings and necklaces. Some lapidaries, including Arthur Anderson, Michael Dyber, and Bart Curren, incorporated matte-finished facets to add an unusual visual texture to cut gems (Anderson, 1991; Johnson and Koivula, 1998, 1999). Cabochon cuts continued to shine in the '90s, as virtually every popular gem material, both transparent and opaque, appeared in a host of different forms, including the standard round or oval cabochon, pyramidal "sugarloaf," and many fancy shapes with buffed crowns and faceted pavilions. Even more radical departures from the standard cabochon became popular, such as flattened "tongues" and elongated bullet shapes, which were cut, for the most part, from chalcedony, garnet, beryl, tourmaline, and quartz.

Gemstone beads made a big comeback during the '90s in single- and multiple-strand necklaces and bracelets. In addition to the standard gem materials found in bead form, a number of additional gems were fashioned into beads as well. These included tanzanite, fluorite, spinel, and transparent labradorite. Beads appeared in many different shapes, such as smooth and faceted spheres, ovals, and lentil shapes, as well as polished cubes, cylinders, hearts, stars, and tumble-polished free-form pieces. In some cases, unpolished elongated rough crystals of aquamarine, green beryl, emerald, tourmaline, or topaz were sliced in chunks and drilled down their central axes as beads. Strung with gold bead spacers in close-fitting necklaces, these made a

Figure 11. Natural polycrystalline surfaces, known as druses, added appeal to fantasy carvings such as this one by Glenn Lehrer. The finished brooch, accented by a 12 mm South Sea cultured pearl and diamonds, resembles the spreading wings of an angel or a butterfly. Courtesy of Glenn Lehrer.

Figure 12. At once ancient and modern in appearance, this magnificent necklace designed by Elizabeth Gage uses aquamarine crystals that have been sliced into chunks, drilled down their central axes, and strung as beads with granulated gold spacers. The eye-catching aquamarine and golden beryl ring is typical of the size and importance of rings in the '90s. Courtesy of Elizabeth Gage, London.

dramatic statement, at once primitive and sophisticated (figure 12). Single-strand, elastic-strung gemstone bead "Buddha" bracelets, also known as power beads, were a brief fashion in the late '90s. Worn singly or in multiples, these bracelets were marketed for their esoteric healing properties ("Feng shwing," 2000).

ORGANIC GEM MATERIALS

Pearls. Pearls were extremely important in the 1990s. When the Akoya cultured pearl industry suffered severe setbacks (Akamatsu, 1999), other pearl growers filled the void, keeping interest high and buying trends strong. Fine round Tahitian black and South Sea "cream" and "golden" cultured pearls in 12–19 mm sizes became very fashionable in high-end jewelry, usually as single-strand necklaces but often as suites, with a matching ring and earrings (figure 13). Drop shapes, in a range of colors, were ideally suited for pendants and earrings, and baroque shapes found immediate acceptance in distinctive brooches, mismatched earrings, and a wide variety of pendants. Previously rejected by the trade as blemished, grooved "circle" cultured pearls also found a ready market in the '90s (Weldon, 1999). The concentric rings provide an interesting texture and are often accompanied by bands of particularly strong orient. Imaginative jewelers, such as Christopher Walling, took blemished cultured pearls of good color and placed small bezel-set rubies, sapphires, or diamonds in the blemishes to enhance the pearl's appearance and improve its marketability.

Many novel uses of pearls were developed and gained acceptance in the 1990s. One particularly unusual example is the faceted cultured pearl, which has dozens of symmetrical facets cut onto its surface (figure 14). Multicolored strands of cultured pearls became fashionable for necklaces and bracelets. Pairs of mabe pearls, set back-to-back in bezels, were strung as necklaces. Cultured abalone mabe pearls, introduced by New Zealand pearl farmers toward the end of the decade, made an appearance in rings, pendants, and earrings. Keshi pearls, the spontaneous by-products of the culturing process, became very popular in necklaces and bracelets (separated by short lengths of chain), as the center gem in rings, and set singly or in clusters for earrings.

The quality of Chinese freshwater cultured pearls improved dramatically during this decade, and by the late '90s they were appearing in a wide variety of shapes and luscious pastel colors. The

Figure 13. Tahitian black and South Sea cultured pearls in the 12–19 mm range became very popular during the '90s in single-strand chokers or in matching suites of jewelry. They were often enhanced by diamonds as shown here. Courtesy of J. Grahl Design; photo by Sylvia Bissonette.

Figure 14. Faceting was applied to pearls for the first time during the '90s. Dozens of facets add a unique dimension to the luster and orient of the black cultured pearls (left 14 mm, right 13 mm) in these two sculpted gold rings designed and fabricated by Katey Brunini of Solana Beach, California. Photo by Maha Tannous.

most notable were nearly spherical with high luster (figure 15), which equaled or surpassed Akoya cultured pearls in beauty (Federman, 1999b).

The U.S. freshwater pearl industry also gained attention in the '90s by introducing new shapes for cultured pearls. These included the flat disc, heart, rectangle, and pear, in addition to the standard oval, button, and baroque. Subsequently, China began producing coin-shaped freshwater cultured pearls ("Lucoral launches coin pearls," 1998).

Other Organic Gems. In the 1980s, the use of ivory and tortoise shell was curtailed as elephants and hawksbill turtles were put on the endangered species list and given governmental protection. Fossilized Mammoth ivory, from animals already extinct, was used sparingly in place of elephant ivory. Coral, on the other hand, was overfished dur-

Figure 15. By the end of the decade, China was producing large, nearly spherical freshwater cultured pearls of high luster. Some of the finest examples appeared in a range of delicious pastel hues that became fashionable in multicolored strands such as the 10.0–12.6 mm Chinese freshwater cultured pearls shown here. Courtesy of King's Ransom, Sausalito, California; photo © Harold & Erica Van Pelt.

Figure 16. Coral, out of vogue for most of the 1990s, began to stage a modest comeback in jewelry toward the end of the decade. Pavé-set old-cut diamonds give definition to the assembled branches of polished red coral in this unusual brooch. Courtesy of designer Lina Fanourakis, Athens, Greece.

ing the 1980s, and the resulting glut of material on the market put many dealers out of business as prices dropped (Grigg, 1993). Because overfishing also depleted many known sources for coral, environmental concerns put a further deterrent on trade as it became politically incorrect to use fine coral in jewelry. Only in the latter part of the 1990s did coral begin to make a modest comeback (figure 16).

Relatively ignored in prior decades, amber suddenly became popular following the huge success of the 1993 Steven Spielberg film, *Jurassic Park*, from the novel by Michael Crichton. The story was based on the premise that dinosaurs could be cloned using DNA from blood found in mosquitoes that had been trapped in amber. Demand for amber soared, and material from the Baltic Sea as well as the Dominican Republic and Brazil was fashioned into beads of every size and shape, or set in simple silver jewelry ("New popularity for amber…," 1994).

PRECIOUS METAL TRENDS

Platinum. The most significant change in the use of precious metals during the 1990s was a shift in marketing emphasis from yellow gold to white metals—platinum, white gold, and silver. In the early '90s, platinum became the metal of choice for Japan, at that time the strongest world market for jewelry. In the U.S., the shift toward platinum in jewelery began gradually, as it appeared first mixed with yellow gold. By the end of the decade, however, platinum used alone was more prevalent, particularly in bridal jewelry and fine gemstone jewelry in the upper price ranges ("The platinum report," 1998; see figure 17 and the cover of this issue). Some jewelers, such as Michael Bondanza, developed lines of less-formal platinum jewelry to suit the more casual lifestyle of the '90s.

Gold. Gold dominated the market, however, and the shift toward the use of higher-karat fineness continued. Whereas 14K gold continued to be popular in jewelry for the American mass market, 18K and 22K yellow gold became the norm for higher-end jewelry and in artist jewelry that used such techniques as granulation and weaving (figure 18;

Figure 17. There was greater use of platinum for jewelry during the 1990s, particularly in high-end pieces such as this impressive pavé diamond brooch by Ella Gafter. Courtesy of Ellagem, New York; photo by Harold & Erica Van Pelt, © GIA.

Figure 18. Higher-karat gold became more prevalent in the '90s, especially among artist jewelers who incorporated the techniques of granulation or weaving. This "crown" pendant by Barbara Berk was hand woven of 18K and 22K gold using a method derived from "Soumak," an ancient rug-weaving technique; it is set with a 14.07 ct pink tourmaline briolette, and Akoya and freshwater cultured pearls. Courtesy of Barbara Berk Designs, Foster City, California; photo by Dana Davis.

Figure 19. Silver jewelry gained a higher profile among young professionals. Designer David Yurman's distinctive Cable Collection answered the need for jewelry that was casual yet dressy. These two penannular bracelets from his "Blue Ice" collection combine sterling silver with 18K gold, pavé diamonds, and blue chalcedony "tongues" as terminals. Courtesy of David Yurman Designs, New York.

see also figures 1 and 7). Twenty-four karat gold also was used more frequently, both for accents in white metal jewelry, and on its own in necklaces, bracelets, and earrings.

Different gold hues were used to pavé set gems of like color in a new type of monochrome jewel that appeared during the '90s. This was manifest first as yellow diamonds set in yellow gold, pink diamonds set in rose gold, and colorless diamonds set in white gold instead of platinum. However, the fashion soon extended to include colored gems as well. Jewelers such as Ralph Esmerian, Graff, and J.A.R. (Joel Arthur Rosenthal) spearheaded the style in the early '90s, but others adopted the trend and expanded on it as the decade advanced (Proddow and Fasel, 1996).

Silver and Other Metals. Silver jewelry was especially popular with the teen and young professional market. Bold and powerful pieces were set predominantly with amethyst, citrine, garnet, aquamarine, moonstone, tourmaline, and different varieties of chalcedony. Often, touches of yellow gold were used to give the jewelry a more sophisticated look. Designer David Yurman's line of silver jewelry augmented by touches of gold captured the market for young professionals who were looking for strong, dramatic jewelry that they could comfortably wear anywhere with anything (figure 19; Okun, 1998). His efforts to brand his distinctive "cable" look were so successful that he became a household name during this decade. Silver also was used to set diamonds, rubies, and sapphires, a practice that had been out of fashion since the introduction of platinum for jewelry in the late 19th century. In a style initiated by J.A.R., diamonds and fine colored stones were pavé set in blackened silver to give it an antique appearance.

Other metals also were used in jewelry during the 1990s. Titanium, which enjoyed a flurry of interest as a refractory metal in jewelry of the mid-'80s, began to be used to pavé set diamonds and colored stones. Because titanium is durable and strong, but lighter in weight than platinum, gold, or silver, it can be used to fabricate large pieces that are still comfortable to wear (Thompson, 1998). The husband-and-wife team Emmanuel and Sophie Guillaume (E.S.G.), use titanium in large brooches that are exquisitely pavé set with colored gems and diamonds (figure 20). They also occasionally use iron in jewelry, along with gold and platinum, as they feel that "iron provides the right amount of rigidity and stability for certain parts of large pieces" (E. Guillaume, pers. comm., 2000).

Figure 20. Titanium is a perfect metal for mounting gems in large pieces of jewelry. Designed by Sophie Guillaume and fabricated by Emmanuel Guillaume, of E.S.G., this butterfly brooch is completely covered with demantoid garnets and diamonds pavé set in titanium. The quality of workmanship is evident in the fact that the piece is as beautiful from the back (inset) as it is from the front. From the collection of Michael M. Scott; photo by Harold & Erica Van Pelt.

SETTING STYLES

In addition to pavé work, other ways of mounting gemstones—bezel settings, tension settings, flush mountings, and invisible settings—were prevalent in the 1990s. In high-end jewelry, the pronged setting that was typical gave way to a new preference for bezel-set diamonds and colored stones. Tension settings, introduced by Niessing in the 1980s, became more widespread as they were adopted by a number of other companies. Steven Kretchmer of the U.S. holds a patent on his technique, which secures the gem under 12,000 pounds of pressure per square inch (Thompson, 1996). Only diamonds, rubies, and sapphires that have been individually selected to be free of certain inclusions can withstand this type of setting. There was also a fashion for very small melee diamonds set flush with the surrounding metal as accents in jewelry. These flush-mounted diamonds were placed in loose arrangements on the shanks of rings, on the edges of cuff bracelets, or on individual links of chain necklaces and bracelets, so that the pieces appear to have been dusted with sugar or stars (figure 21).

The Mystère setting for diamonds, introduced by Bunz of Germany, was also highly innovative.

Figure 21. Using his patented technique, metallurgist/jeweler Steven Kretchmer has tension set diamonds in platinum for his Jazz bracelet and Omega ring. The bracelet also incorporates matte-finished 18K gold links and is accented by 24K crystallized gold and flush-mounted diamonds, while the ring has two spots of purple gold and flush-mounted rubies on its shank. Courtesy of Steven Kretchmer, Palenville, New York; photo by Harold & Erica Van Pelt, © GIA.

Figure 22. The Mystère setting, developed by George Bunz, was an innovative version of tension setting for diamonds that appeared during the 1990s. The stone is placed between a "fingerlet and opposing thumb" so that it is securely held and yet can be rotated in the mounting. Courtesy of Bunz, Dobel, Germany.

Figure 23. In anticlastic raising, a technique developed in the '80s by Michael Good, the metal is hammered so that it curls in opposing directions. In the '90s, Good began to set gems in his distinctive anticlastic jewels, giving them added dimension. This ring, set with a Context-cut diamond, looks streamlined but is technically complex, a trait shared by many jewels in this eclectic decade. Courtesy of Michael Good Designs, Rockport, Maine.

The diamond is seated with its culet in a cone-shaped cup and its table held by a point of metal almost as if the stone were held between thumb and forefinger. This allows the diamond to rotate in the mounting while it is nevertheless safely held in place (figure 22). Michael Good, whose unusual technique of anticlastic raising was a breakthrough style in the 1980s (Blauer, 1985), began to add gems to the fluid loops of his jewelry. In anticlastic raising, a flat sheet of 18K gold or platinum is cut in various shapes and then hammered so that the center is compressed and the edges are stretched, causing the metal to spread and coil into deceptively simple curvilinear jewels (Good, 1985). During the '90s, Good began to set baguette diamonds along the seams of his bracelets and rings, and placed single gems—often a Context-cut or Spirit Sun diamond—in the center of rings or pendants, forging the metal so that it curled back and held the gem firmly in place (figure 23; see again figure 4).

NEW TECHNOLOGY EXPANDS: LASERS AND COMPUTERS

Lasers, introduced in the 1970s as a diamond-cutting tool, were applied to jewelry manufacture by such pioneers as Martin Stuart (Weldon, 1992). As the decade progressed, laser technology advanced and equipment became more affordable, so more jewelers used lasers for jewelry manufacture and repair. The enormous advantage of the laser is that a bench jeweler can make delicate repairs to jewelry set with heat-sensitive materials without having to unmount all the gems. Because the laser's ray is tiny and concentrated, it can make pinpoint solder joints or welds without distributing much heat, which minimizes the risk of damage (Todd Bracken, pers. comm., 2000). This was a major breakthrough for the repair of antique and estate jewelry set with pearls, channel-set colored stones, or pavé diamonds, which otherwise would be extremely time consuming, if not impossible, to accomplish.

The computer became an essential tool for everyone in the '90s. At the same time that e-business exploded on the Internet, computers became indispensable in areas such as inventory control, gem grading, appraisals, and—most notably—in the design and manufacture of jewelry. CAD/CAM (computer-aided design/computer-aided manufacture) made it possible to design a piece of jewelry in three dimensions on the computer screen and have

the image translated into wax that could be cast, molded, and produced in multiples—a tremendous time-saver for mass-manufacturing jewelry companies (Thornton, 1998).

JEWELRY STYLES

Styles were exceptionally varied in the last decade, ranging from conservative traditional jewelry to sleek, ultramodern designs to one-of-a-kind pieces by contemporary artist-jewelers. Antique and estate jewelry was also in strong demand. The exceptional popularity of estate-style jewelry prompted many jewelers to produce replicas to make the look available to every level of buyer. Designs from the early 20th century—platinum, diamond, and pearl pieces inspired by the garland style, for example, or plique-a-jour enameled pieces designed to imitate Art Nouveau jewels—were especially prevalent.

Texture Talks. There was a strong interest in jewelry with the look of fabric in the '90s. Metal was woven, braided, or fashioned into interlocking mesh and accented by diamonds, pearls, or colored gems. Jewelry by Christian Tse, among others, exemplifies this, in gem-studded mesh collars, chokers, and bracelets (figure 24). Woven metal also achieved the fabric look in jewelry by such artists as Arline Fisch, Barbara Berk, and Mary Lee Hu. Using wire or narrow strips of 18K or 22K gold, these jewelers produced tight patterns and curving volutes of woven metal (again, see figure 18).

Metal was also given surface textures to mimic the appearance of satin or woven ribbon. While this technique has been a standard practice in recent decades for such jewelry luminaries as Buccellatti and Henry Dunay, a greater number of jewelers picked up the trend and expanded on it in various ways. The surfaces of some high-karat gold bracelets and earrings by Lina Fanourakis, for example, appear identical to that of a finely ribbed grosgrain ribbon. Other jewelers, such as Alex Sepkus and Paul Lantuch, are known for their elaborate, hand-engraved surface textures. Some jewels by Sepkus have the look of braided or woven ribbons of gold accented by small diamonds and colored stones, while others have the rich complexity of an intricate tapestry. Lantuch's jewelry is reminiscent of Renaissance gold work, with superbly carved scrollwork and mannerist images from the 16th century. A loupe is needed to properly admire the exquisite detail on pieces by these artists.

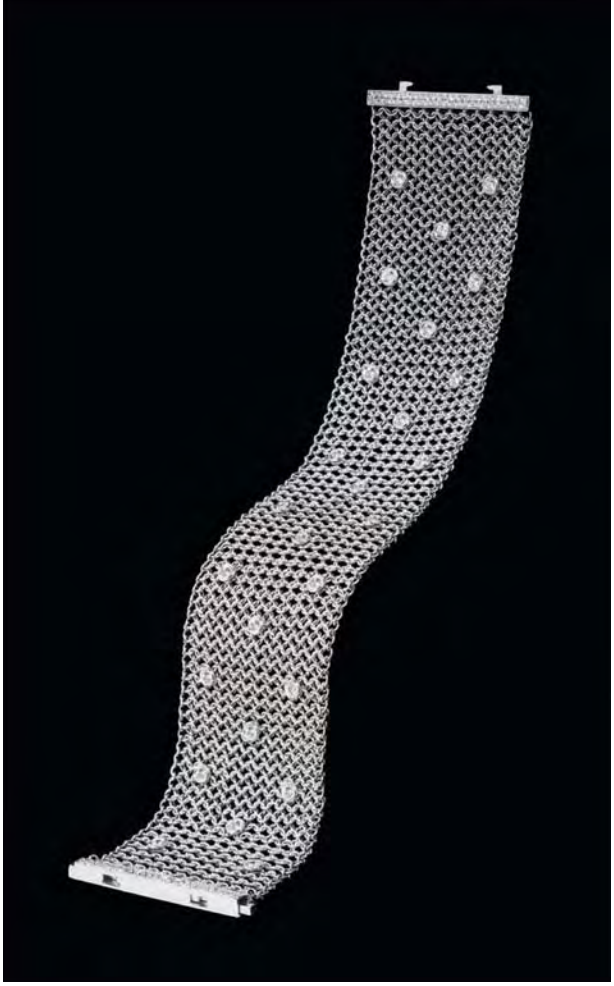

Figure 24. The look of fabric was a strong trend in jewelry during the '90s. Designer Christian Tse became known for his jewels of woven platinum or gold mesh set with diamonds or colored stones. This bracelet of platinum mesh, enriched by a pattern of bezel-set diamonds, has a cool elegance that exemplifies the cloth-like trend. Courtesy of Christian Tse, Los Angeles.

Pavé. Pavé work appeared everywhere in jewelry of the 1990s. Links in bracelets and chain necklaces—and even the shanks and prongs of rings—were pavéed with diamonds. Some designers also used colored gems extensively in their pavé work (again, see figure 20). In a style unique to this decade, different gems of similar color were used in combination with each other. For example, rubies, red spinels, and rubellites of the same size, cut, and color tone might be used to completely cover the surface of a jewel. Similarly, blue gems—such as tanzanites, iolites, and sapphires—or green gems—such as tsavorites, demantoids, tourmalines, and emeralds—would be used to fill fields in a design. In variations on this theme, these gems might be set so they shaded from light to dark tones or from one hue to

Figure 25. Multi-gem pavé jewelry was introduced in the '90s and became very fashionable. Different gems of like color and size were pavé set in one of three ways: to completely cover a jewel, to fill different areas with contrasting color, or to provide gradations from one hue to another. These leaf earrings, designed by Michelle Ong of multi-gem pavé in platinum and blackened silver, are perfect illustrations of this style. The gems used are fancy brown and yellow diamonds, blue and pink sapphires, rubies, emeralds, and amethyst, accented by near-colorless diamonds. Courtesy of Michelle Ong for Carnet, Hong Kong; photo © Tino Hammid.

another. Pioneered by J.A.R. at the start of the decade, this style was adopted by a number of designers, including Marilyn Cooperman, Delle Valle, James de Givenchy, E.S.G., Martin Katz, and Michelle Ong (figure 25). Occasionally, the gems would be set with the pavilion up and the crown down for a distinctive look.

Trompe l'Oiel. New to the '90s was the "trompe l'oiel" effect of overlaid gems seen in the work of Michael Zobel of Germany and British designer Stephen Webster. Jewelry by Zobel features yellow diamonds set in platinum or rose gold, all of which is covered by a thin sheet of amber or mother-of-pearl that allows the diamonds to glisten through (figure 26). Webster's method is to set carved rock crystal saddles or cabochons on top of a flat slab of tiger's-eye, chrysoprase, lapis lazuli, jade, or opal to give the finished composite jewel a soft, illusive color effect (figure 27).

Jewelry Motifs. Motifs during the decade fell into several groups. There were simple, blocky-style hearts, stars, moons, crosses, cylinders, cubes, and teardrops—minimal and solid with rounded or beveled edges. These were either pavéed or scatter-set with gems. Some were inlaid with onyx, turquoise, mother-of-pearl, or coral. In representations of the natural world, there was particular emphasis on endangered or exotic species, including the elephant, rhinoceros, panda, giraffe, panther, tiger, alligator, whale, and seal. Although hardly endangered, the lowly snail appeared frequently in precious form, while jeweled butterflies, bees, turtles, fish, and frogs were as prolific as ever. Companies such as Cartier, Graff, and Bulgari made a variety of jewels in this vein. Flora as well as fauna thrived in jewelry designs. Delicate flowers such as lilies, orchids, and camellias were especially popular in both stylized and actual representations (Flores-Vianna, 1998). Natural figures in jewelry were predominantly fashioned in metal set with pavé diamonds, but they also frequently incorporated baroque-shaped cultured pearls or carved gems with colored gem or enameled accents.

Crosses and crowns were featured in a number of popular styles, notably by such designers as Cynthia Bach and Erica Courtney among many others. Ribbon and bow motifs extended the fabric look popular in the '90s, while the appearance of jeweled baby shoes and pacifiers was one indication of the huge baby boom among young professionals.

Necklace styles ranged from close-fitting chokers to chains 16 to 24 inches (40 to 61 cm) in length. Big gold-link necklaces or flexible gem-set collars—which fit close around the base of the neck—were "must-have" items at the start of the decade. They were eclipsed somewhat in the late '90s by minimalist pendants and lavalieres that accentuated a long, lean look. Gem-set chains and gem-bead necklaces became more popular as the decade pro-

gressed, while pearls of every type were omnipresent in every style. The fashionable "Y-necklace" that captured the market in 1996 was passé by 1997, replaced by the lariat—a long, open-ended chain fastened with a gem-set slide-clasp or tied loosely around the neck to show gem-set terminations (Morreale, 1997).

Set with diamonds or colored gems, line bracelets, also known as "tennis" bracelets, continued to be popular in the '90s. An endless variety of flexible link bracelets of all widths were in vogue, particularly with diamonds pavéed on alternate links. Big cuff bracelets were also popular, both rigid and in flexible mesh. C-shaped, penannular bangles, with gem-set terminals worn to show at the top of the wrist, were also a '90s trend; they were seen particularly in jewelry designs by Steven Lagos and David Yurman (again, see figure 19).

In general, rings were large and designed to "stand out in a crowd" (see again figure 12). The antique look of pierced platinum with hand-engraved details was strongly favored for engagement rings, while a channel-set or invisibly set shank surrounding a large center stone was a more dazzling modern style, and ultramodern tension-set or Mystère-set diamonds were at the vanguard. Colored gem rings tended to be big, bold, and richly set with gems in strong color combinations. J.F.A. (Jean-François Albert) came out with his Signature Fit shank for large gem-set rings that can be adjusted to fit different finger sizes. Domed rings set with individual square cabochons or individual pearls in a gold grid—for a quilted appearance—extended the fabric look to rings. Large center gems were set in chunky metal rings and worn on the index finger for a power look. Some of the most avant-garde rings of the '90s were carved from a gem material such as quartz or chalcedony and then set with a different gemstone (Koivula and Kammerling, 1991). Although this has historic precedent in rings from the Mughal period in India and from the 1920s in Western Europe, the '90s rings have a raw power that is at once barbaric and futuristic.

Earrings shifted in fashion from large, close-fitting clips as the decade opened—to long pendants by the time it closed (figure 28). Diamond stud earrings were ubiquitous, growing larger in carat size as the decade wore on. Single baroque-shaped black or "cream"-colored cultured pearls were ideal for drops at the end of a simple shepherd's-hook ear wire. Large, single, round cultured pearls of good color

Figure 26. This pendant, by Michael Zobel, demonstrates the "trompe l'oeil" layered gems that appeared in jewelry during the 1990s. Centered around a large gray Tahitian cultured pearl and terminating in a faceted 0.43 ct black diamond, the brooch incorporates a rose gold and platinum disc set with flush-mounted diamonds overlaid by a thin mother-of-pearl sheet that allows the diamonds to shine through softly. Courtesy of Michael Zobel, Konstanz, Germany.

and luster, set with a single bezel-set diamond of a half-carat or more, also were fashionable. Earrings were often "unmatched": fabricated so that the design was the same for both but the gems were opposite. For example, one earring might contain a black pearl top with white pearl drop, while the other has a white pearl top with black pearl drop. Both men and women wore earrings during the '90s, with many sporting more than one earring in each ear, although this was generally a radical fashion statement that had abated somewhat as the decade came to a close.

Impact of Competitions. Jewelry design competitions played an important role in the promotion of diamonds, pearls, and colored stones during this decade. The Diamonds International awards hosted by De Beers, and the Pearl competitions hosted by the Cultured Pearl Association, are venerable among international competitions. Others are regional, including the Swiss Prix Golay Buchel and the North American Spectrum awards hosted by AGTA. The heightened exposure that these competitions gave to jewelry from each of these regions inspired additional contests in the '90s, including the above-mentioned AGTA Cutting Edge awards for innovation and excellence in gem cutting, the Platinum Guild International's Platinum Passion awards to inspire designs in platinum, the World Gold Council's Gold Virtuosi awards to honor designs in gold, and the Women's Jewelry Association Diva award to promote jewelry designed by women. Photo spreads featuring the winning pieces are given much play in the trade press, and the pieces themselves are put on exhibit—often at a number of different venues. This exposure has helped advance the use of colored gems in fine jewelry and the proliferation of pearls, as well as expanded the popularity of diamonds and platinum.

Figure 27. In another version of the "trompe l'oiel" effect, Stephen Webster sets faceted or carved quartz cabochons over thin slices of chrysoprase and lapis lazuli to give an illusive color effect, as illustrated in these rings of 18K gold enhanced by diamonds. Courtesy of Stephen Webster, London.

Auction Trends. Traditionally, auction houses were the venue for the sale of ancient, antique, and previously owned estate jewelry to a narrow group of antique- and estate-jewelry dealers and collectors. During the 1990s, however, there was a gradual shift in both the type of buyer at an auction and the type of jewelry sold there. Sotheby's sale of the Duchess of Windsor's jewelry in 1987 brought jewelry auctions into the limelight and heightened public awareness of auctions as a source of fine jewelry. Other highly publicized estate auctions fanned the flames, and soon wealthy buyers from the public sector began to outbid estate jewelers for these pieces (Dick, 1990b). This new trend was a double-edged sword: While it focused public attention on antique and estate jewelry, thereby escalating prices and demand, most estate-jewelry dealers were unable to pay the higher prices at auction and still make a profit in resale. As a result, there were more buyers from the private sector but fewer estate-jewelry dealers bought pieces at auction.

Meanwhile, manufacturers of contemporary jewelry, seeing a ready market that they could exploit, began to discreetly place newly fabricated jewelry in the auction sales. For expensive, high-end pieces by new designers, auction houses provided access to a much wider clientele of wealthy buyers. They also brought new designers immediate international exposure, a visibility that would otherwise be difficult and expensive to achieve in the intensely competitive '90s market. As a result, a number of contemporary designers, including Della Valle,

Michelle Ong, and Lynn Nakamura, are beginning to build international followings through the auction market. Symbiotically, auction houses are benefiting by showcasing a select group of contemporary jewelry artists and designers (Christie's, 2000; Sotheby's, 2000).

MARKETING AND THE MEDIA

Marketing was of paramount importance for designers in this highly competitive decade. The best way for them to become known was to advertise their designs so that the consumer would immediately connect their name with a particular style. Branding became a trend at every level of the industry: Argyle "champagne" diamonds, the Lazare Diamond, Cartier and Tiffany & Co. jewelry, and individual designers such as Henry Dunay and David Yurman. As if the competition wasn't fierce enough, fashion couturiers such as Chanel, Versace, Fendi, Gucci, and Escada also came out with lines of fine jewelry. While this latter development put greater pressure on jewelers to compete for market share, it also tied jewelry into the clothing fashion scene, building a greater awareness of contemporary styles for jewelry among the wealthy followers of couture fashion.

With the growing importance of movies and television, and the proliferation of print media, jewelry trends became instantly accessible to everyone. This immediacy of information has had a homogenizing effect in many ways, making certain looks and styles generic worldwide. The power of Hollywood had to be recognized, as jewelry worn by actresses on television and in movies immediately set trends for the greater public. The "Y" necklace, popularized by various TV series such as *Friends,* is a case in point, as is the pearl floater necklace by Wendy Brigode that actress Rene Russo wore in the films *Tin Cup* and *Ransom* (Morreale, 1997). Pearls spaced two to three inches apart on fine silk cord or monofilament became a huge success for Brigode and such companies as Honora.

The Academy of Motion Picture Arts and Sciences Annual Awards ceremony has become a huge opportunity for jewelers, as the movie stars who attend get extraordinary media coverage through live television on the night of the event and subsequently in print by such publications as *InStyle*, *Movieline*, and *People*. Harry Winston, Fred Leighton, David Orgell, and Martin Katz are some of the prominent jewelers who have loaned jewelry for stars to wear on Oscar night. Others design pieces for their clients for such a special event, as Cynthia Bach did for Cate Blanchett on Academy Awards night in 1999.

Figure 28. Long earrings became fashionable again in the late 1990s. This dramatic pair, fabricated of textured 18K gold and platinum, is augmented by bezel-set diamonds, inlaid black nephrite jade, and keshi cultured pearls. Courtesy of Richard Kimball Designs, Denver, Colorado; photo © Tino Hammid and GIA.

Television shopping networks and the Internet have also brought a wide selection of jewelry directly to the masses. Buying jewelry and gemstones has never been easier. With a simple telephone call or the click of a mouse, items shown in photographic detail can be purchased instantly. Home Shopping Network and QVC were two of the first television marketing networks where jewelry could be purchased with a phone call. They combined their jewelry displays with information about the gem materials used, which raised public awareness of the wide

variety of colored gems. Although most of what was initially offered was on the low end of the value scale, the jewelry world could hardly ignore the tremendous marketing potential of these venues.

In the late 1990s, jewelers at every level scrambled to put a Web site on the Internet and make a bid for the online consumer (Haley, 1996). By late 2000, however, two of the most prominent sites had folded, and several more were reputed to have only a few months' financial viability left (D. Hiss-Odell, pers. comm., 2000). The Internet is a new frontier for the jewelry world, with inherent opportunities and risks. Aware of the potential, however, many jewelry companies are willing to gamble on a dot-com Internet business in the hopes of striking it rich. At this point, the Web sites vary widely in what they offer and how they make their services available to the public. Much like the false-fronts on the boomtown shacks of America's Wild West a century ago, some Web sites are nothing more than an advertisement with a phone and a fax number. Others, by comparison, are sophisticated promotional and informational venues with multiple layers that can be explored with deft application of a computer mouse.

CONCLUSION

Defining jewelry trends of the 1990s could be compared to defining the continually shifting shapes in a kaleidoscope. This was a decade packed with change. New, often unusual cuts for diamonds and colored gems proliferated, expanding the possibilities for jewelry design, which took off in every direction. Designers used new juxtapositions of colored gems set in a wide range of metals, from platinum to 24K gold to titanium. Gold and white metals vied for pride of place in the marketplace, while diamonds and colored gems in pavé, flush, invisible, and tension settings gave '90s jewelry a variety of distinctive looks. As the sources for cultured pearls expanded, so did their impact on the market. And the marketplace itself expanded to include television and the Internet, which have had a profound influence, while jewelry branding became the best way to get consumer attention.

Looking ahead, this is an intensely exciting time for the jewelry industry, with many burgeoning opportunities and creativity at every level. Doubtless, the tremendous advances in the '90s will have a decided impact on jewelry design, manufacture, marketing, and wear in the decade to come.

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Key to abbreviations: *American Jewelry Manufacturers* = *AJM*; *Gems & Gemology* = *G&G* (Gem News = GN); *Jewelers' Circular Keystone* = *JCK*; *Modern Jeweler* = *MJ*.

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