

VOLUME XLI

# GEMS & GEMOLOGY

FALL 2005



*Featuring:*

*Diamond Industry Review  
French CVD Synthetic Diamonds  
Inclusions in Rhodonite*

THE QUARTERLY JOURNAL OF THE GEMOLOGICAL INSTITUTE OF AMERICA



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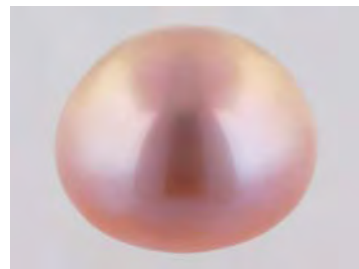
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## ABOUT THE COVER

Since the late 1980s, the world diamond market has undergone enormous changes at every level. The lead article in this issue, by GIA senior industry analyst Russell Shor, chronicles these dramatic evolutions in the industry. Shown here are both classic and new styles of diamond jewelry. The center stone in the solitaire ring is 7.02 ct; the eternity ring, the choker necklace, and the earrings contain 15.34, 30.01, and 22.55 ct of colorless diamonds, respectively; and the bracelet contains 3.04 ct of pink and 11.74 ct of colorless diamonds. The rings are courtesy of Jerry Blickman Inc., the necklace is courtesy of Rwiat Inc., and the earrings and bracelet are courtesy of Ishaia Trading Corp., all of New York. Photo © Harold & Erica Van Pelt and GIA.

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# Shifting Tides in the Diamond Industry

The Fall 1988 issue of *Gems & Gemology* contained an article titled “An Economic Review of the Past Decade in Diamonds.” In it, I chronicled the extraordinary, now historic, ups and downs of the diamond market from the mid-1970s to the late 1980s.

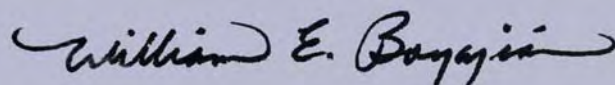
When it was published, the article surprised many *G&G* readers in that it deviated from the purely scientific or gemological nature of the journal. But, as the late Richard T. Liddicoat wrote in that issue’s editorial, “Today . . . the study of gemology is more than refractive indices and specific gravity; it goes beyond synthetics and simulants, localities and Leveridge gauges. Gemology is now a truly interdisciplinary profession, requiring a good balance of the technical, aesthetic, and commercial aspects of gems.”

GIA’s Russell Shor, a respected journalist who has spent more than 20 years following the diamond industry, continues this spirit of gemological breadth and depth in our current issue. His article is a comprehensive review of the vast economic and social forces that have shaped the diamond industry since the late 1980s. During these years, a veritable revolution has taken place. From production and distribution changes, to major market shifts toward India and China, to the branding revolution, conflict diamonds, terrorism threats, and the Kimberley Process, this article is a must-read for any serious jeweler or gemologist, especially one who wants to see today’s diamond industry in its most transparent form.



Of all the changes discussed in this article, none can compare to the fundamental shift in the role of De Beers from custodian of global diamond supply to market driver. With its Supplier of Choice initiative, a response to the many economic and geopolitical forces Shor describes, De Beers abandoned the philosophy that had guided the company for more than a century—controlling supply in order to protect demand. The mere fact that the De Beers brand name is now reserved for its retail partnership with LVMH (De Beers LV) is a monumental change in thinking all its own.

I believe Shor’s work will stand as the most practical resource on diamond industry developments over the turn of the millennium, and will intrigue readers for years to come. As with all *G&G* articles, especially those that lead an issue, we demand a significant contribution to the gemological and jewelry literature. The broadening of gemology itself and the ramifications of economic, social, geopolitical, and technological factors in our trade qualify Shor’s article as such, and again demonstrate the diverse and multifaceted nature of our field.



William E. Boyajian, President  
Gemological Institute of America

# A REVIEW OF THE POLITICAL AND ECONOMIC FORCES SHAPING TODAY'S DIAMOND INDUSTRY

Russell Shor

During the past 15 years, political and economic forces have converged to radically transform the structure of the diamond industry worldwide. This article examines how upheavals in the former Soviet Union and several African nations—as well as the arrival of new sources such as Australia and Canada—led to the restructuring of the rough diamond market. This in turn created new competitive pressure at the wholesale and retail levels, including the movement to establish new diamond cuts and diamonds as branded items. At the same time, technological advances have enabled the faster, more efficient manufacturing of rough diamonds, created new treatments, and fostered the introduction of economically viable gem-quality synthetics. While demand for diamond jewelry remains strong in the U.S., which accounts for nearly 50% of world consumption, new markets such as India and China are likely to spearhead continued growth. In addition, new social and governmental initiatives have affected how the entire industry conducts business.

In the Fall 1988 issue of *Gems & Gemology*, William E. Boyajian chronicled the price-supply upheavals in the diamond market of the late 1970s and 1980s that set into motion some of the forces that would bring even more radical changes in subsequent years. These included the speculative and “investment diamond” era of the late 1970s, and the subsequent crash that forced a number of firms into bankruptcy. Japanese consumers led the awakening of Asian consumer markets that helped revive the diamond trade in the mid-'80s. In addition, the large output of small, lower-quality diamonds from Australia's Argyle mine, coupled with the exponential expansion of India's diamond manufacturing industry, made diamond jewelry a mass-market item for the American middle class.

This article looks at the many developments that have had an impact on the world diamond industry since the 1980s. Momentous changes in world politics, in particular, have had a profound effect: The end of the Cold War unleashed a competitive spree for Russian rough diamonds; civil wars in some African diamond-producing nations revealed a dark underside of the diamond industry; and the collapse

of several Asian economies in the late 1990s delivered a devastating blow to some diamond operations.

In addition, diamond sources in Australia and Canada were developed by mining companies that challenged De Beers's traditional single-channel sales market. A diamond manufacturer, Lev Leviev, also became a major rival to De Beers by securing lucrative diamond sources in Angola, Namibia, and Russia. De Beers recast its own operations at the turn of the millennium and tried, along with industry bankers, to shift the industry from a supply-driven to a demand-driven mentality, pushing its sightholders to greater vertical integration and investment in sales and marketing programs. Meanwhile, diamond-producing nations began asserting greater control over their resources, including demands that a share of their bounty be processed locally. This has profound implications for diamond manufacturers in all parts of the world, as well as for distributors in the middle

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See end of article for About the Author and Acknowledgments.  
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*Figure 1. Though diamonds have always adorned the wealthy and famous, recent decades have seen a notable increase in the popularity of flashy, “bling-bling” styles of diamond jewelry. Here American singer Beyoncé is shown wearing a dramatic pair of diamond mesh earrings by Lorraine Schwartz, New York, while arriving at the 2005 Academy Awards. Photo © Lisa O’Connor/ZUMA/Corbis.*

of the pipeline. Technological advances during the 1990s made diamond manufacturing vastly more efficient, created new retail avenues that greatly affected the way diamonds were sold, and yielded new treatments and synthetics that challenged gemologists’ skills. Consumers became privy to a vast array of gemological and market information about diamonds, and celebrities made them an even more important element of high fashion (figure 1).

All of these developments are still fluid, and they undoubtedly will continue to bring deep changes to the diamond industry, challenging retailers, dealers, and gemologists to adapt. On the positive side, new, lucrative consumer markets for diamonds have developed and show no sign of slowing, creating immense opportunity amid these challenges.

### **DIAMOND PRODUCTION AND DISTRIBUTION: THE EVOLUTION OF A MULTI-CHANNEL SELLING MARKET**

Some of the most radical changes came in the production and distribution of rough diamonds. In 1991, worldwide production totaled approximately 106

million carats (table 1). The majority of world production was concentrated in southern Africa, with other sources including Australia and the Soviet Union (Levinson et al., 1992). Through its single-channel marketing approach, formally adopted in 1935 (“Diamonds,” 1935), De Beers still managed the distribution of the vast majority of rough diamonds entering the world market. Yet within 10 years, changes in De Beers’s relationships with Russian and Australian producers, the development of mines in Canada, and political events in Africa would dramatically reduce De Beers’s share of the market and greatly alter the entire dynamic of the diamond industry (Even-Zohar, 2002). The map of world diamond production and major cutting centers that Boyajian published in 1988 (p. 149) has undergone some significant changes (figure 2).

**De Beers’s Central Selling Organisation/Diamond Trading Company.** Since 1888, De Beers has been the world’s primary supplier of rough diamonds. As recently as 1993, the De Beers Central Selling Organisation (CSO) controlled about 80% by value of the approximately \$5.5 billion world market,

through ownership of its own mines in South Africa (see, e.g., figure 3) and 50-50 partnerships in mines with the governments of Botswana and (since 1994) Namibia (Austin, 1994; Shor, 2004). In addition, the CSO marketed all of Russia's rough diamond exports, as well as all official production from Zaire's (Democratic Republic of the Congo [DRC] after 1996) Minière de Bakwanga (MIBA) mine and Angola's state-owned diamond-mining company, Endiama. It also maintained buying offices in most African producing nations and Brazil to buy rough on the open market. With one exception (the Argyle mine), all major diamond production sources were controlled by either De Beers or the governments of the countries in which the mines were located, often in partnership with one another. The 20% of rough traded outside the CSO came from independent shares of Argyle; small mining operations in South

Africa, South America, and elsewhere; informal alluvial mining in West Africa; and market "windows"—a percentage of rough diamonds the CSO permitted its contracted producers to sell on the open market to gauge prices.

The CSO mixed rough diamonds from all sources and sorted them by quality, shape, and weight criteria (figure 4). Ten times yearly, it marketed rough to a specific roster of clients at "sights." In times of slack demand or overproduction, the CSO would act as a market buffer by stockpiling diamonds or reducing their purchases from certain producers (effectively forcing them to stock at the mine sites).

Yet several forces were developing that would significantly affect the CSO's ability to maintain a majority share of the rough diamond market, hold stocks of rough to regulate price fluctuations, and fully control rough diamonds it obtained from its

**TABLE 1.** World rough diamond production by country, 1991–2003 (in thousands of carats).<sup>a</sup>

Country	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
<b>Gem and near-gem</b>													
Angola	899	1,100	130	270	2,600	2,250	1,110	2,400	3,360	3,914	4,653	4,520	4,770
Australia	17,978	18,078	18,844	19,485	18,300	18,897	18,100	18,400	13,403	11,956	11,779	15,142	14,900
Botswana	11,550	11,160	10,310	10,550	11,500	12,400	15,100	14,800	17,200	18,500	19,800	21,300	22,800
Canada <sup>b</sup>	—	—	—	—	—	—	—	300	2,429	2,534	3,716	4,984	11,200
Zaire/D. R. Congo	3,000	8,934	2,006	4,000	4,000	3,600	3,000	3,300	4,120	3,500	3,640	4,400	5,400
Liberia	—	—	—	—	60	60	80	150	120	100	100	48	36
Namibia	1,170	1,520	1,120	1,312	1,382	1,402	1,345	1,394	1,630	1,450	1,487	1,350	1,650
USSR/Russia <sup>c</sup>	10,000	9,000	8,000	8,500	10,500	10,500	10,500	11,500	11,500	11,600	11,600	11,500	12,000
Sierra Leone	160	180	90	155	113	162	300	200	7	58	167	147	214
South Africa	3,800	4,600	4,600	4,340	5,070	4,400	4,500	4,300	4,000	4,320	4,470	4,350	5,070
Other	2,433	2,737	2,612	2,746	2,117	1,853	2,568	2,235	2,883	3,300	3,122	2,888	2,910
Total	51,000	57,300	47,700	51,400	55,700	55,500	56,600	58,900	60,600	61,200	64,500	70,600	80,900
<b>Industrial</b>													
Angola	62	80	15	30	300	250	124	364	373	435	517	502	530
Australia	17,978	22,095	23,032	23,815	22,400	23,096	22,100	22,500	16,381	14,612	14,397	18,500	18,200
Botswana	4,950	4,790	4,420	5,000	5,300	5,000	5,000	5,000	5,730	6,160	6,600	7,100	7,600
Zaire/D. R. Congo	14,814	4,567	13,620	13,000	13,000	17,000	17,600	18,900	16,000	14,200	14,560	17,456	21,600
Liberia	—	—	—	—	90	90	120	150	80	70	70	32	24
Namibia	20	30	20	—	—	—	71	73	—	106	—	—	—
USSR/Russia <sup>c</sup>	10,000	9,000	8,000	8,500	10,500	10,500	10,500	11,500	11,500	11,600	11,600	11,500	12,000
Sierra Leone	83	116	68	100	101	108	100	50	2	19	56	205	296
South Africa	4,600	5,600	5,700	5,343	5,880	5,550	5,540	6,460	6,010	6,470	6,700	6,530	7,600
Other	2,300	2,206	2,488	2,561	2,505	2,663	2,201	2,326	1,553	1,646	1,621	1,638	1,632
Total	54,800	48,500	57,400	58,300	60,100	64,300	63,400	67,300	57,600	55,300	56,100	63,500	69,500
<b>Grand total</b>	<b>106,000</b>	<b>106,000</b>	<b>105,000</b>	<b>110,000</b>	<b>116,000</b>	<b>120,000</b>	<b>120,000</b>	<b>126,000</b>	<b>118,000</b>	<b>117,000</b>	<b>121,000</b>	<b>134,000</b>	<b>150,000</b>

<sup>a</sup> Totals may not match individual values because of rounding. A "—" in a block indicates no production or negligible production reported. Sources: Balazik (1995); Olson (1999, 2003). Note that other sources may use different numbers because much of the information is based on estimates.

<sup>b</sup> Total production. Separate figures for industrial diamonds not available.

<sup>c</sup> All Russia/USSR data before 2003 are based on estimates, with output believed to be 50% gem and 50% industrial.

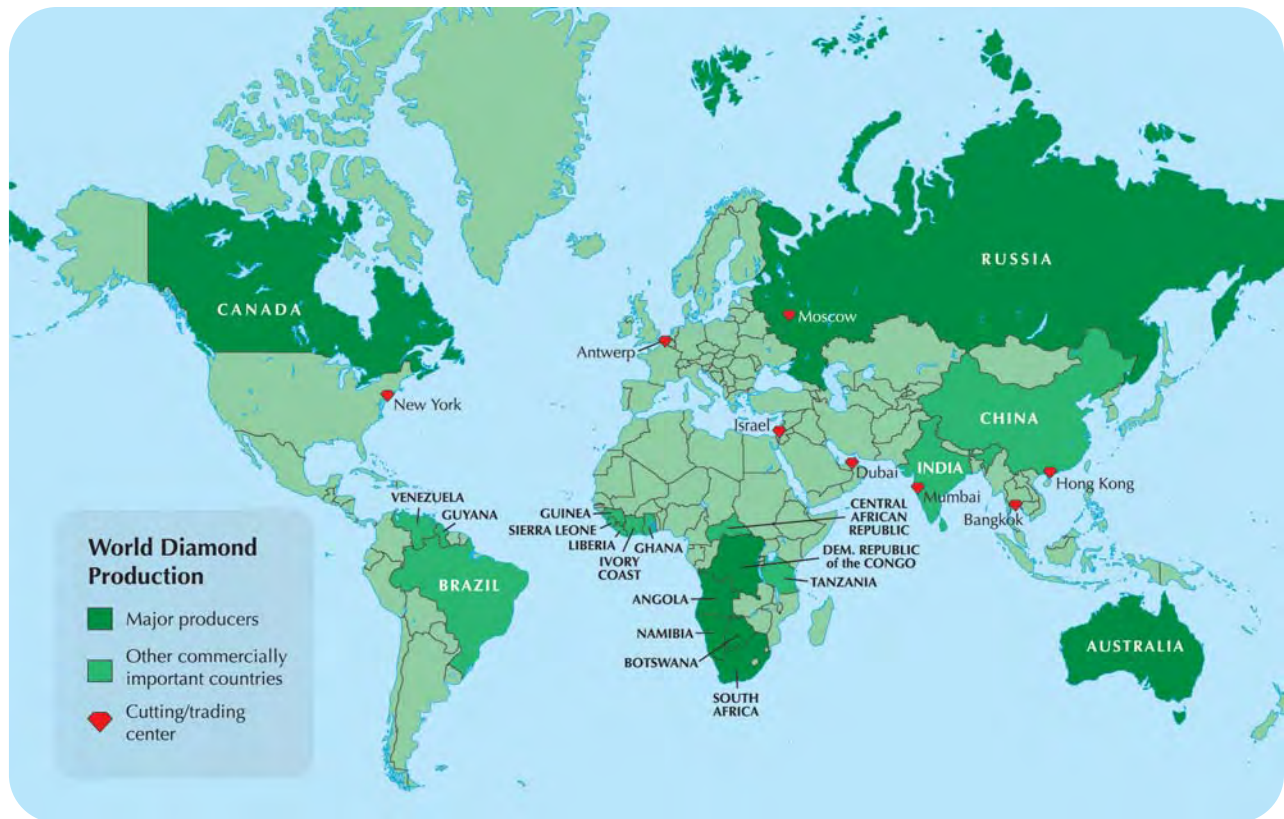


Figure 2. Diamond production in the 1980s was largely concentrated in southern Africa, with a few major mines in Australia and the USSR. There are now major producing countries (dark green) on every continent except South America and Antarctica; these eight countries accounted for over 95% of world production by volume in 2003. Approximately a dozen other countries (medium green) produce commercially significant amounts, though far less than the major producing nations. The major cutting and trading centers are indicated with a red diamond. Modified from Boyajian (1988).

own mines. First, the end of the Soviet regime unleashed a torrent of rough diamonds from the country's stockpiles and a desire among a number of Russia's senior government officials and members of the diamond hierarchy to become more independent.

Second, a temporary truce in Angola's decades-long civil war during the early 1990s created an opportunity for thousands of *garimpeiros* (independent miners who often use only rudimentary tools), many of them recently demobilized soldiers, to dig for diamonds in the country's alluvial fields. Suddenly hundreds of thousands of carats of diamonds, typically of better qualities, were being sold through offices in Luanda and Antwerp. The CSO reportedly bought some \$600 million of such goods to remove them from the market (and thus keep prices stable) in 1996 alone (Shor, 1996d). This decision caused an abrupt increase in De Beers's diamond stocks, drawing criticism from the financial community. Although the CSO purchased Angolan diamonds using its own funds, without borrowing,

investors believed such a stockpile was a growing liability, and the price of the company's stock ultimately fell because of it (De Beers Consolidated Mines, 1997). In addition, because De Beers executives had made the high-quality goods flowing from Angola such a priority, they were disinclined to protect the market for small diamonds. This concerned Argyle executives and contributed to their decision not to renew their marketing agreement with the CSO (Shor, 1996c).

Third, the discovery of diamonds in Canada introduced a large rival mining corporation, BHP, to the diamond market, thus creating another formidable distribution channel outside the CSO.

Finally, after 1999 the CSO (renamed the Diamond Trading Company, or DTC, in 2000) stopped buying goods on the outside market in order to reduce its large diamond stockpile, which had grown to \$4.8 billion (De Beers Consolidated Mines, 2000). In addition, it did not want to handle so-called conflict diamonds from embattled nations





Figure 3. De Beers's historical dominance of the rough diamond market is founded on its ownership of several large mines in South Africa. Shown here is the Venetia mine north of Messina, where full production of 3.6 million carats was achieved in 1993. Venetia is South Africa's most productive diamond mine and one of the most modern diamond mining facilities in the world. Courtesy of the DTC.

(discussed below). By this action, the company put the industry on notice that it would no longer serve as custodian for the trade

Thus, as the 21st century opened, De Beers's share of rough diamond sales had been reduced sharply to some 50% by value, ending its role as single-channel marketer and reducing its ability to regulate supplies and prices—particularly of polished goods under a carat.

**Russia.** One of the most significant and tumultuous events of the late 20th century was the collapse of the Soviet Union in 1991–92. Under the Soviet system, government agencies closely controlled all diamond operations. Since these goods first reached the international market around 1963 (Even-Zohar, 2002), the Soviets sold most of their diamond production to the CSO through intermediaries. In the 1970s, they developed their own diamond-cutting facilities and, by 1978, about \$400 million of their production was allocated to these ventures (EIU, 1979).

Soviet diamond-mining and marketing operations remained fairly stable until the mid-1980s, when then-premier Mikhail Gorbachev embarked on an ambitious program—*perestroika*, or restructuring—to modernize the Soviet economy. As part of this program, in 1990 De Beers agreed to loan the Soviets \$1 billion. As collateral, a significant portion of the USSR's diamond stockpile was transferred to De Beers's CSO headquarters. The deal also included a five-year agreement allowing De Beers exclusive marketing rights to new diamond production (Shor, 1993).

The end of the Soviet regime led to a new diamond industry structure that divided power and profits between the central government in Moscow and the local authority in Sakha, the semi-autonomous republic that produces 98% of Russia's diamonds. The mining and marketing of diamonds from the Russian Federation was placed under a "joint-stock" (cooperative venture) agency known as Almazzirossi-Sakha (now shortened to Alrosa), Russian for "Diamonds of Russia and Sakha." Ownership of Alrosa is divided as follows: Sakha Republic, 40.5%; the central Russian government, 32.5%; other government agencies, 27%.

Alrosa took 80% of Russia's yearly rough production of approximately \$1.2 billion; the Republic of Sakha took the other 20%. Those shares continue today. With the dissolution of the USSR, Alrosa continued to honor a clause in the 1990 agreement with De Beers that required it to sell 75% of its rough production to the CSO. The remaining 25% would go to Russian polishing operations or be sold through Alrosa's office in Moscow. At the same time, Sakha signed its own contract with the CSO to sell all of its production, apart from a provision for unspecified allocations to local polishing operations. This would prove problematic.

The 1990 agreement contained several critical loopholes: It did not include goods from Russia's estimated \$3 billion stockpile, which were administered by a different agency controlled by the central government (Komdragmet, later called Gokhran); it did not define or limit the scope of "domestic" polishing operations (most of which were in fact newly

created joint ventures with Antwerp or Israeli manufacturers); and it did not include sales of “technical” (industrial) diamonds (Shor, 1993).

By 1992, diamonds were pouring through these loopholes, depressing prices—particularly of small goods. Worse for De Beers, some of the 37 cutting operations did little more than polish a window onto a rough diamond and export it as “polished” (Even-Zohar, 2002). An estimated \$5 billion worth of rough diamonds thus leaked into the market during the mid-1990s (Pearson, 1998). The influx of so many diamonds caused serious instability in the diamond market.

In October 1997, after two years of difficult negotiations, the Russian government and the CSO finally signed a new contract that would last until the end of 1998. It was based on a complex formula stipulating that Russia, through Alrosa, sell the CSO a minimum of \$1.2 billion of rough diamonds, drawn from both new mine production and the stockpile. The agreement closed two crucial loopholes: It banned the export of partially manufactured diamonds, and it tightened the standards for “technical” diamonds so they were much

closer to the trade’s definition of *industrial* (Shor 1997b, 1998a).

After 1997, Alrosa shifted its priorities to the 90 domestic diamond-polishing factories operating in Russia, including several it established through a subsidiary, Brillianty Alrosa. That company alone sold \$130.7 million in polished diamonds in 2001 (Alrosa, 2002).

De Beers and Alrosa concluded another five-year agreement in 2001, which required that the latter sell De Beers a minimum of \$800 million worth of rough annually, approximately half of Sakha’s total production (De Beers Consolidated Mines, 2001). However, the following year, the European Commission (the executive body of the European Union) began a lengthy review process to determine whether or not this supply arrangement violated anti-competition regulations. While the matter remains pending, De Beers and Alrosa agreed to a substantial phased reduction of their rough diamond dealings, with Alrosa selecting “approximately 15 clients” to supplement De Beers (Rapaport, 2004b). The result certainly will thrust Alrosa into a more competitive stance against the DTC as the decade progresses.

At the opening of 2005, the Russian government issued official diamond production figures for the first time ever. In 2003, 33.02 million carats (Mct) of rough was produced, valued at \$1.7 billion (an average of \$51 per carat; this figure is higher than those given in table 1, which are based on earlier data). Interestingly, for the same year, Russia listed rough exports of 37.8 Mct valued at \$883.4 million, or \$23 per carat (“Russian diamond production...,” 2005), which indicates that it was still selling large stocks of industrial and lower-quality cuttable diamonds from its stockpile.

**Australia.** Australia’s Argyle diamond mine was developed in the early 1980s. The sheer volume of the mine’s production—42 Mct yearly at its peak—served as a catalyst for a number of important changes in the world diamond market. In particular, the millions of carats of predominantly small near-gem diamonds (very low quality rough from which some gem material can be extracted) coming from Argyle provided the raw material for the exponential growth of India’s diamond manufacturing industry. Moreover, the marketing of Argyle’s (predominantly brown) colored diamonds fostered a much greater consumer awareness of such stones.

When the mine began production, its major partners, Ashton Mining and CRA Mining (CRA merged

*Figure 4. De Beers has traditionally brought all its rough diamond production to CSO/DTC headquarters in London, where it is mixed and sorted into thousands of categories before distribution to sightholders. This practice is being challenged, as producing nations seek to retain a portion of their rough for local cutting and polishing. Courtesy of the DTC.*





with RTZ in 1995 and took the name *Rio Tinto* two years later), signed a deal to sell the CSO 75% of their yearly output. Approximately 40% of these diamonds could be fashioned into polished goods—albeit, for the most part, of very low quality—by India's low-wage manufacturing force (the effects on India are detailed below). At first, these vast quantities of smaller, lower-quality material were easily absorbed by fast-growing U.S. mass merchandisers, who found a market niche for affordable diamond jewelry. However, Argyle production neared full capacity by 1991 as the U.S. economy fell into a recession, swelling inventories of small diamonds in the cutting centers. Then the large, unregulated flow of small diamonds from Russia in the early and mid-1990s (discussed above) depressed prices and bloated inventories, prompting De Beers to impose a 25% reduction in its purchases of rough from each producer (Shor, 1996b). The move generated unease among Argyle executives, who believed De Beers had failed to support the market for small diamonds at the same time that it had propped up the market for larger diamonds when supplies of such goods from Angola threatened to overwhelm the pipeline.

As a result, Argyle declined to renew its sales contract with De Beers in 1996. This decision sent fears of a price war between the CSO and Argyle circulating through India's diamond industry.

Argyle also broke precedent with other diamond producers by launching its own marketing campaign, beginning in 1990 (Shor, 1991). The company developed a sales organization and marketing initiatives aimed at driving demand for smaller diamonds and the millions of carats of brown goods the mine produced, which it christened "champagne" and "cognac" (Shor, 1991; figure 5). Argyle then focused on promoting finished jewelry made by major purchasers of its diamonds, hiring jewelry manufacturing technicians to assist these firms in developing products and services compatible with American retailers' requirements (Shor, 1994) and engaging a marketing organization (Market Vision International [MVI]) to facilitate access to U.S. retailers at major trade shows. By 2004, India's diamond jewelry exports had topped \$2 billion, nearly two-thirds of which were destined for U.S. retailers (Weldon, 2004a).

While achieving success at building demand for its clients' products, Argyle's owners were faced with a critical decision as the millennium neared: The projected "life" of the mine's open-pit operation (figure 6) was coming to an end. Production had nearly



Figure 5. During the 1990s, a series of marketing initiatives by the owners of the Argyle mine in Australia helped make fine brown diamonds such as these (0.35–1.32 ct) an important segment of the colored diamond market. Photo © Robert Weldon.

halved to 26.2 Mct by 2001, after Rio Tinto conducted a redevelopment project to extend its life. This reduction in Argyle's output created a large overcapacity of diamond manufacturing in India, which touched off a heated competition for rough supplies to keep the many operations going (Gross, 2003). By mid-2005, the projected cost of converting Argyle into an underground mine was estimated at A\$1.05 billion (US\$800 million). Rio Tinto has pressured the Western Australian government for aid and concessions on the 22.5% it pays in royalties to keep the mine operating past 2008 (Tanna, 2004a; "Argyle expansion..." 2005). Closure of Argyle would exacerbate the overcapacity of India's diamond-manufacturing operations, particularly in Ahmadabad, where vast quantities of those stones are polished.

**Canada.** The 1991 discovery of diamond-bearing kimberlite at Lac de Gras in Canada's Northwest Territories was the first significant diamond find in North America. Ultimately, the Canadian mines would become the first major operations in recent times to sell the majority of their production outside the CSO from the beginning.

By the time the mine finally opened in October 1998, BHP Minerals (now BHP Billiton) had established a marketing subsidiary, BHP Diamonds, which opened a sales office in Antwerp, run in cooperation with rough diamond dealer IDH Diamonds (Shor, 1999). In the first two years of operation, Ekati's main pipe, Panda, yielded a total of 2.7 Mct, about 2% of world diamond production by weight and 5% by value. By 2003, annual production had increased to 4 Mct, worth just over \$600 million (Rio Tinto Diamonds, 2003).



In 1999, BHP Diamonds signed a three-year agreement with the CSO to market 35% of the mine's production by volume. At the end of that agreement, BHP chose to market its entire production itself (Even-Zohar, 2002). BHP now distributes the vast majority of its production through its Antwerp sales office in a manner similar to the DTC sights: selling to a regular clientele at scheduled intervals. In a break from the existing DTC policy, however, BHP announced it would adjust prices to market forces. (Through much of Ekati's life, however, downward adjustment has not been necessary [G. Nicholls, pers. comm., April 2004].)

The discovery of diamonds at Ekati touched off a huge exploration rush that resulted in the discovery of another major deposit nearby. Aber Resources Ltd. located a cluster of kimberlite pipes under a lake just southeast of the Ekati concession. The site, later named Diavik, was promising enough to attract Rio Tinto as a 60% partner. Tiffany & Co. also took a stake in the venture (see below for details).

With the opening of Diavik (figure 7) in 2003, Canada became the world's sixth largest diamond producer by volume (an estimated 12.6 Mct in 2004) and third by value (an estimated \$1.6 billion), according to Even-Zohar (2005).

Following Ekati's lead, Rio Tinto chose to market its own production directly rather than through the DTC. As discussed above, by then the company had developed a sophisticated marketing operation for its Argyle production, giving it a ready-made sales organization with extensive contacts throughout the diamond pipeline, from Indian manufacturers to American retailers.

**New Competitors: Lev Leviev, LLD.** One of De Beers's principal competitors to emerge in the late 1990s was a former client, Lev Leviev (figure 8), who had set a goal of establishing a truly independent diamond operation. This required owning or controlling sources of rough diamonds (Weldon, 2002).

In 1989, Leviev, a naturalized Israeli citizen born in Uzbekistan, found his first diamond source close to his homeland. His company, then known as LID, formed a joint-venture diamond manufacturing operation with Alrosa. The venture, called Ruis (short for Russia/Israel), had direct access to Russia's rough diamond resources. Eventually, Leviev acquired full control of Ruis, which in 2002 manufactured \$140 million in polished goods (Berman and Goldman, 2003). The release of Russian rough to cutting operations during the early 1990s was the



*Figure 6. The huge volume and unique characteristics of Argyle's production have wrought enormous changes in the diamond market over the past two decades, from driving the growth of India's polishing industry to supplying greatly increased numbers of fancy-color diamonds. The Argyle open-pit mine is nearing the end of its production life, and its potential closure in the next decade is a source of uncertainty in the markets it helped create.*

catalyst that helped Leviev become the first significant competitor to De Beers in the control and distribution of rough diamonds.



*Figure 7. In little more than five years, Canada's diamond production grew from negligible to third in the world by value. Total 2004 production at the Diavik mine on Lac de Gras in the Northwest Territories (left) exceeded 7 million carats. Photo by Mark L. Craigshead.*

As Ruis expanded, Leviev secured ever-greater amounts of rough, from both Alrosa and Komdragmet/Gokhran. In 1999, he invested the profits from this operation in contracts to obtain

*Figure 8. Former De Beers sightholder Lev Leviev built a multi-billion-dollar diamond mining and manufacturing company during the 1990s through his partnerships with Russian and Angolan diamond producers. LLD Diamonds is now second only to De Beers in rough diamond sales worldwide. Photo by Robert Weldon.*



rough from another major diamond producer, Angola (Berman and Goldman, 2003).

Leviev took advantage of De Beers's departure from Angola in 1998 to gain access to its diamond production. He presented a plan to Angola's government to increase revenues by marketing diamonds through a single entity. The Angola Selling Corp. (Ascorp) was created from this initiative, and the government awarded Leviev a 25% stake in it (Weldon, 2002). Leviev also won a share of Sodiam, an Angolan government agency set up to buy diamonds from alluvial concessions, which then marketed its diamonds through Ascorp.

Since 2000, Leviev has also invested heavily in offshore diamond mining in Namibia and obtained contracts to market rough from the Democratic Republic of the Congo (see below). These operations helped his company, now called LLD Diamonds, achieve about \$1 billion worth of rough diamond sales in 2002 (Even-Zohar, 2002), putting him ahead of such major diamond producers as Rio Tinto and BHP Billiton. In 2004, Leviev expanded his diamond manufacturing operation to Namibia, where he purchased a deep-sea mining operation, and announced plans to open a polishing facility in Botswana.

In 2005, however, Leviev's position as principal marketer of Angolan diamonds was challenged by Israeli manufacturer Dan Gertler, of DGI Group, which won a contract to sell 300,000 carats monthly from the country's largest mine, Catoca (Helmer, 2005). In addition, De Beers reestablished its exploration and mineral rights in the diamond-bearing province of Lunda Norte (Miller, 2005b).



**African Producers.** De Beers's biggest challenge in the coming decade will be to adapt to demands from the governments of South Africa, Namibia, and Botswana to exert greater control over their respective diamond resources and obtain more domestic benefits (primarily increased employment) from De Beers's diamond-mining operations. At mid-decade, producer-country governments, the DTC and, to a lesser extent, other mining companies are still in difficult negotiations over an effective balance between local beneficiation and economically efficient enterprise. Ultimately, this could cause De Beers and other mining concerns working in these nations to sort and market the bulk of their productions locally, instead of mixing them in a central facility, as is the current practice. The outcomes remain far from certain; however, the shift toward local diamond manufacturing undoubtedly will affect pricing, profits, and the availability of goods throughout the entire diamond pipeline.

*South Africa.* In 2002, 10.9 Mct of diamonds were mined in South Africa, 95% by De Beers-controlled mines (Coakley, 2002). As 2005 began, South Africa's legislature was debating a controversial initiative designed to bring much greater beneficiation to the country, and it had mandated that blacks share in the ownership of the country's mineral resources, including diamonds. This legislation package is an important part of the government's Black Economic Empowerment (BEE) policies,

which seek to integrate the country's majority population into its large corporate community (Mbeki, 2004; Mlambo-Ngcuka, 2004).

The legislation would put into practice principles espoused in the country's new Mining Charter, which asserts that all mineral resources are the property of the people of the country, with the state holding custodial rights. The laws would cede broad discretionary powers to the minister of minerals and energy in granting and administering prospecting and mining operations, require mining companies to set aside a percentage of rough diamonds for local manufacturing, and allow domestic cutters first refusal rights on rough diamonds.

Then-minister of minerals and energy (now deputy president) Phumzile Mlambo-Ngcuka (figure 9) told attendees at the 2004 Antwerp Diamond Conference that "local cutters should be empowered to decide what they can and cannot cut rather than producers who are keen to sell outside [South Africa]" (Mlambo-Ngcuka, 2004). However, experiences in Canada's Northwest Territories (NWT) demonstrated the difficulties of such operations. In 2005, Sirius Diamonds, a cutting facility established with aid from the provincial NWT government, went bankrupt. De Beers chairman Nicky Oppenheimer, addressing a gathering of African mining ministers on February 8, 2005, noted that diamond manufacturing in high-wage countries (e.g., South Africa) can run \$40-\$50 per carat, yet must compete with large,



*Figure 9. The end of apartheid helped bring about significant changes in the diamond industry's once-intimate relationship with the South African government. In recent years, government officials such as president Thabo Mbeki (left) and deputy president Phumzile Mlambo-Ngcuka (right) have forcefully lobbied for greater local benefits for the South African people, such as black ownership of mining resources and expanded local cutting operations. Photo © Mike Hutchings/Reuters/Corbis.*



automated Indian operations, where costs run \$10–\$12 per carat (Robinson, 2005a). Thus, governments would be forced to subsidize the operations with tax revenues or by requiring the industry to allow such operations to “cherry pick” material that can be profitably manufactured, leaving less-profitable material for manufacturers in other cutting centers (Pearson, 2004; Priddy, 2005).

Although Oppenheimer further noted at the February 2005 meeting that heavy-handed legislation could lead to “disengagement” between the government and mining companies, the company hastened to comply with South Africa’s demands. In June 2005, the DTC added five South African sightholders for a total of 19 in that country. These additional sights were allocated to companies compliant with South Africa’s BEE programs, which include black partners or substantial black investment (Miller, 2005a).

The governments of Namibia and Botswana also have called for beneficiation projects within their borders, though far less sweeping than South Africa’s proposals (Even-Zohar, 2004; Benson, 2005).

*Figure 10. As African governments seek greater local benefits from their diamond resources, one primary goal is the successful development of local polishing operations. Shown here is a sawing line at the Namcot Diamonds plant in Windhoek, Namibia, operated by the Steinmetz Group. The economic viability of these operations is uncertain, since they must compete with manufacturers in countries such as India that have much lower labor costs. Photo by Brendan Laurs.*



*Namibia.* This country has been a producer of high-value marine diamonds for nearly 100 years. Production averaged about \$275 per carat in 2000 (Even-Zohar, 2002). After Namibia achieved independence in 1990, newly elected president Sam Nujoma negotiated with De Beers, which owned all of the major diamond-producing concessions, to transform mining operations into a 50-50 government-De Beers corporation called Namdeb, created in 1994. Nujoma later encouraged other diamond producers and manufacturers to invest in the country, with the eventual goal of having 90% of Namibian-mined diamonds polished locally. As of mid-2005, five local polishing operations (see, e.g., figure 10) had been established, including a 550-worker facility opened by Lev Leviev.

At a November 2004 ceremony in Windhoek, De Beers managing director Gary Ralfe offered to help the government develop skills and jobs in the country, which produced 1.65 Mct in 2003 (Tanna, 2004b). In mid-2005, Ralfe opened a branch of Diamdel, the DTC’s rough diamond distribution subsidiary, in Windhoek to supply local diamond-manufacturing operations (De Beers Group, 2005).

*Botswana.* De Beers and the Republic of Botswana have been partners in the world’s largest diamond reserves since 1967. There are three major diamond mines in the country—Orapa, Jwaneng (figure 11), and Letlhakane—and a smaller, newly opened operation, Damtshaa. These are owned jointly by De Beers and the government of Botswana through a 50-50 venture, Debswana.

The sheer volume of Botswana’s production, 30.4 Mct valued at \$2.4 billion in 2003 (Debswana, 2003), combined with the fact that diamond revenues account for 35–40% of the country’s gross domestic product, have placed the two entities into an interdependent relationship. This was formally sealed in 2001 when Botswana became the first diamond producer to gain an ownership stake in De Beers. Debswana took a direct 11% share, and an indirect 4% share when De Beers reorganized as a private concern that year (discussed in detail below; De Beers Consolidated Mines, 2001; Even-Zohar, 2002). Botswana president Festus Mogae made it clear in a November 2002 talk in Antwerp that diamonds have been the key to his country’s rapid development and ascendance into a middle-class society, according to World Bank classifications.

Despite their close relationship, De Beers and the government of Botswana have engaged in hard



Figure 11. The enormous production of Botswana's diamond mines, such as Jwaneng (left) has been the key to that country's evolution into a stable middle-class democracy. The imperative to use diamonds to promote development in Africa is an important challenge for the 21st century diamond industry. Courtesy of the DTC.

negotiating sessions over renewals of mining leases and marketing contracts. The cession of Debswana's stake in De Beers to the government was one outcome of the talks over the renewal of the 25-year Jwaneng license in 2004 (Katz, 2004b).

### CONFLICT DIAMONDS

While mining companies and governments vied to develop and control kimberlite deposits, the alluvial fields of western (Sierra Leone), central

(Democratic Republic of Congo [DRC]), and southern (Angola; figure 12) Africa brought to official and public attention, for the first time, concerns over the origins of diamonds. Civil wars in these regions sparked a series of United Nations sanctions on trading diamonds from those countries, beginning in 1998. These stones became known as "conflict diamonds," which the U.N. officially defined in 2000 as: "Diamonds that originate from areas controlled by forces or factions opposed to the legitimate and internationally recognized gov-

Figure 12. One of the most dramatic changes in the diamond industry in recent years has been greater attention to the source of rough diamonds. As governments and rebel groups in Africa increasingly used diamond revenue to fund wars and atrocities, the industry was forced to enact restrictions on rough trading based on where the diamonds were mined. This 2001 photo shows an alluvial pit near the town of Saurimo in Lunda Sul Province, Angola. Photo © Teun Voeten; courtesy of Panos Pictures.





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ernments, and are used to fund military action in opposition to those governments, or in contravention to the decision of the Security Council" (*Conflict Diamonds*, 2001, p. 1).

**Angola.** Shortly after Angola achieved independence from Portugal in 1974, following a revolution led by the Movimento Popular da Libertação de Angola (MPLA), the country fell into civil war. Because of the MPLA's Marxist nature, Angola immediately became embroiled in the Cold War struggle between the U.S. and the Soviet Union. For much of the 1970s, however, the Marxist inclinations of Angola's government did not deter it from continuing the country's relationship with De Beers. By 1980, most of the resistance to Angola's existing MPLA government had coalesced around a former army general, Jonas Savimbi. The general won the support of many organizations in the U.S. with his promise to bring democracy to his country.

During the 1980s, Savimbi's União Nacional para a Independência Total de Angola (UNITA) began targeting the country's diamond operations and selling captured diamonds via networks that ran through Lisbon to Antwerp (Shor, 1986). Angola's state-run diamond marketing agency, then called Diamang, reported that the country's official diamond production had declined nearly two-thirds, to 700,000 carats, by 1986.

In the early 1990s, UNITA and the MPLA government reached a U.N.-brokered accord. When the cease-fire unraveled in 1993, Savimbi and his forces retreated to the eastern end of the country, which includes two major diamond-producing areas, Lunda Norte and Lunda Sul. That same year, the U.N. Security Council adopted Resolution 864 imposing an arms embargo against UNITA and establishing a committee to monitor UNITA's activities.

In 1998, after another failed peace initiative in Angola, the U.N. Security Council adopted Resolutions 1173 and 1176, which prohibited the direct or indirect import from Angola of all diamonds not accompanied by a certificate of origin issued by the government of Angola, and imposing financial and travel sanctions on UNITA and its leaders (Fowler, 2000; *Conflict Diamonds*, 2001). That same year, a London-based nongovernmental organization (NGO), Global Witness, charged that U.N. member states, including Belgium, "were doing very little to enforce the U.N. embargo . . . and are wittingly or unwittingly providing the diamond

industry with the wherewithal to exploit loopholes . . . to maintain the multi-million dollar trade" (Global Witness, 1998, p. 15). Shortly after this, De Beers stopped all purchases of rough diamonds from Angola on the grounds that their legitimate origins could not be verified (De Beers Consolidated Mines, 1999).

**Sierra Leone and the Democratic Republic of the Congo.** In these two countries, diamond production came from two sources: "official" output by government-controlled or sanctioned enterprises, and "unofficial" diggings by *garimpeiros*. Many of these *garimpeiros* were, in effect, workers indentured to local officials or dealers (Shor, 1988a). In the DRC (formerly Zaire), all the official diamond production went through MIBA, the government-dominated agency that controlled large alluvial concessions along the country's southern border with Angola. However, *garimpeiros* occupied most of the other diamond areas, out-producing MIBA by as much as three times in terms of value. This deprived the state of millions of dollars in revenues because most of these diamonds were either smuggled out of the country or, if legally exported, greatly undervalued (Shor, 1986). These diamond-producing areas were the targets of incursions by troops from neighboring countries in 2001–2003.

By the late 1990s, a civil war in Sierra Leone began escalating into a series of horrific atrocities. The Revolutionary United Front (RUF), under Foday Sankoh, broke a year-long cease fire by systematically killing or mutilating the populations of entire villages in the country's diamond-producing areas. The RUF's tactics galvanized the international human rights community into pressuring the diamond industry to act against conflict diamonds.

On November 1, 1999, U.S. congressmen Tony Hall and Frank Wolfe introduced legislation (the CARAT Act) that would require importers of rough and polished gem diamonds and diamond jewelry to provide written certification of the country in which the diamonds were mined (Rapaport, 1999).

As the fighting in both Angola and Sierra Leone intensified, the U.N. issued a report on the conflicts, directed by Canadian ambassador Robert Fowler (2000). The report detailed how rulers of countries neighboring Angola profited by allowing rebel groups to export diamonds through their countries despite the sanctions. Following this report, human rights groups claimed that as much as 15% of all diamonds in the market were "conflict;" De



Figure 13. The Kimberley Process requires that all diamonds crossing the borders of KP-participating countries be accompanied by a certificate such as the one shown here (a sample issued by the United Arab Emirates). The certificate must warrant that the diamonds have been purchased from legitimate sources not involved in funding conflicts and in compliance with U.N. resolutions.



Beers estimated the number at about 3% (Shor, 2000). The difference lay in the fact that the NCOs counted all diamonds traded outside legitimate channels (known as “illicit” diamonds) as “conflict,” while De Beers counted only those coming from Angola’s and the DRC’s war zones.

**The World Diamond Council and the Kimberley Process.** During July 17–19, 2000, the World Federation of Diamond Bourses (WFDB) and the International Diamond Manufacturers Association (IDMA) established the World Diamond Council (WDC), a representative body comprised of diamond manufacturers and industry organizations such as the HRD, Jewelers of America, the Jewelers Vigilance Committee (JVC), and CIBJO, among others. GIA, as a nonprofit public benefit corporation, also provided assistance, particularly with technical information. The council was charged with developing policies and procedures that would allow the industry to help U.N. and government efforts to end the trade in conflict diamonds.

In December 2000, representatives from diamond-producing nations (including South Africa, Botswana, Russia, Namibia, and the official governments of Sierra Leone and Angola) and diamond-processing nations (including Belgium, Israel, India, and the U.S.) convened in Kimberley, South Africa. After some initial objections by producing countries, the representatives agreed to work toward a scheme that would allow diamonds from nonconflict areas to be traded freely once

their origins were certified. Their efforts to make this plan a reality came to be known as the Kimberley Process (KP).

Fifty-three nations ratified the Kimberley Process at a meeting in Interlachen, Switzerland, in November 2002. The certification requirements took effect January 1, 2003. To participate, nations had to require that all rough KP diamonds passing through their borders carry KP certificates (see, e.g., figure 13). In addition, no imports would be permitted from nonparticipating countries. Critics of the Kimberley Process, including NGOs and the U.S. General Accounting Office, believed the certification scheme was meaningless without independent verification (Smillie, 2002).

By 2003, the governments of Angola, Sierra Leone, and the DRC controlled enough of their diamond resources that they could join the Kimberley Process and use diamond revenues to help rebuild their countries. Even though the Kimberley Process expelled the Republic of the Congo in July 2004 for noncompliance with its procedures, its chairman noted that the KP still covered 99.8% of global diamond production (Martin, 2004). Non-KP producers reportedly accounted for no more than 250,000 carats; the majority of these non-KP goods originated from countries, such as Liberia and the Republic of the Congo, that border diamond-producing nations and have traditionally been used as conduits for illicit diamonds. Although the conflicts that led to the creation of the KP have ended, the KP’s continued role will be that of preventing the use of diamonds to

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support future armed conflicts by keeping them out of illicit channels (Martin, 2004).

**Terrorist Attacks, 9/11, and the PATRIOT Act.** The broader subject of illicit diamonds became more critical after the terrorist attacks of September 11, 2001, when allegations of diamond-funded terrorism became an issue, and the U.S. government began investigating funding sources of al Qaeda and other terrorist organizations. Although reports by Global Witness (2003) and *Washington Post* reporter Douglas Farah (2004) linked certain Lebanese diamond trading firms to terrorist organizations, subsequent investigations turned up no evidence of sustained, ongoing diamond trade by terrorists or their sympathizers.

The final report of the National Commission on Terrorist Acts, the official U.S. body investigating the 9/11 attacks, was released on July 22, 2004. The 585-page report stated that there was “no persuasive evidence that al Qaeda funded itself by trading in African conflict diamonds” (National Commission on Terrorist Attacks, 2004, p. 171).

The 9/11 attacks were also the catalyst for legislation requiring that the financial industry show greater accountability in its international dealings. The Uniting and Strengthening America by Providing Appropriate Tools Required to Intercept and Obstruct Terrorism (USA PATRIOT) Act was signed into law October 26, 2001; one of its many purposes was to curb funding of terrorist organizations. Under authority granted by the Act in April 2002, the U.S. Treasury Department designated gem and jewelry dealers as “financial institutions” and subjected the industry to extensive reporting requirements. In response, the JVC took on the role of liaison between the gem and jewelry industry and the Treasury Department to draft rules that would “accommodate the unique nature of the industry” (Gardner, 2004).

In June 2005, the U.S. Treasury Department Financial Crimes Enforcement Network (FinCEN) issued its Interim Final Rule, which requires that all dealers engaged in the business of purchasing and selling precious metals, stones, and jewels adopt certain procedures to ensure they are not aiding money laundering. FinCEN exempted U.S. retail jewelers who purchase gemstones and jewelry exclusively from U.S.-based dealers on the grounds that these suppliers were already covered.

The European Union and other countries have adopted similar measures. Today, proponents of

African development are looking to the Kimberley Process and anti-money laundering regulations to ensure that diamonds are exported through legitimate channels, which has the added benefit of allowing producing governments to derive the maximum possible revenues from their diamond resources.

## MANUFACTURING TECHNOLOGY

Until the early 1990s, the process of polishing diamonds had changed little from traditional methods developed during the previous century. Most diamond-cutting procedures were still accomplished by hand (Caspi, 1997). The main exception was the automated polishing machine for round brilliants, introduced by Piermatic in the 1970s. During the late 1980s, however, a confluence of events and technologies revolutionized the diamond-cutting process, allowing goods to come to market much more quickly and efficiently. They also increased yield significantly, by giving manufacturers many more options, and permitted new shapes to be fashioned economically.

The most important event was the rise of Indian and other Asian manufacturers in the quality-diamond field, which forced diamond manufacturers in so-called traditional centers, Israel in particular, to look at automating their operations to remain competitive. Indian labor costs ran one-fifth to one-sixth those of Israeli workers (Caspi, 1997). In addition, Asian consumers—the Japanese in particular—were very sensitive to the quality of diamond cut (Shor, 1996e). Moreover, as price competition among retailers intensified, diamond manufacturers were compelled to derive the maximum yield from their rough without sacrificing beauty.

Israeli engineers adapted emerging technologies of lasers, computer imaging, and precision measurement systems to diamond processing. Major producers such as Argyle and De Beers also made improvements in automated diamond-processing equipment, such as polishing and brutting machines, to increase speed, accuracy, and quality (Caspi, 1997).

Lasers had been used by diamond manufacturers since the 1970s to remove dark inclusions, but those early lasers lacked the precision to be adapted to the cutting process, resulting in losses of about 8% of the rough (compared to 1% to 2% by conventional sawing). By the 1980s, though, some manufacturers in India adapted lasers for kerfing (cutting



the groove for cleavers), which accomplished in minutes what took traditional hand workers several hours, and was more accurate. In addition, one laser unit could process 20 diamonds at one time (Shor, 1988b). By the early 1990s, a single technician using a laser system could out-produce 60 hand workers (S. Doshi, pers. comm., 2005).

In the late 1980s, several machines were developed that could automatically brute round diamonds, while still employing the traditional process of grinding one diamond against another (see, e.g., figure 14). These machines replaced traditional bruters, who were among the most skilled and best-paid cutters because they were responsible for deriving the maximum yield. However, even highly skilled bruters produced diamonds that were often slightly out of round, which created problems for faceting machines. Not only did the automatic bruting machines largely solve this problem, but they also helped manufacturers reduce labor costs considerably.

Hand-in-hand with the improvements in the bruting process came the development of automatic centering devices. These could accurately align the rough diamond with the center of the bruting machine, allowing for more precise cutting to manufacturers' requirements and fewer interruptions in the bruting process to readjust a diamond's position on the dop.

By the early 1990s, two things had happened: (1) lasers had improved, with a narrower beam that reduced burn-off; and (2) imaging technology was adapted to allow for precise direction of the laser beam. With these advances, diamond manufacturers could fashion virtually any shape directly from the rough. While greatly speeding up the processing time, as mechanical systems did for round stones, laser bruting of fancies has allowed diamond manufacturers to achieve better symmetry and experiment more freely with new cuts.

Computer technology also transformed the marking process, by which the cutter plans how to divide a crystal most economically. An Israeli company, Sarin, introduced computerized scanning and measuring devices (see, e.g., figure 15) that provided complete measurements of a rough diamond within seconds. The unit scanned the crystal, then evaluated all the possible polished stones that could be derived from it, reducing the need for hand marking and improving yield in the process. In addition, a new generation of automatic grain-finding polishing machines allowed for faster pol-



Figure 14. Bruting, or initial shaping of the rough, was once the most difficult and labor-intensive element of diamond manufacturing. The advent in the 1980s and '90s of automatic bruting machines, such as this one by Milano Industries, led to huge improvements in productivity and quality control. Photo by James E. Shigley.

ishing and much better finish as well as for highly accurate symmetry and faceting.

Although such technological innovations meant that diamond manufacturers had to spend millions of dollars outfitting new factories during a time when competition was squeezing profits, they also allowed the production of polished stones with much better symmetry and finish than ever before. This proved to be a catalyst for a consumer revolution that began in Japan and ultimately spread worldwide: premium-cut diamonds.

Figure 15. Once a matter of expert guesswork, the marking and dividing of rough diamonds became a far more precise and efficient process through the development of computerized scanning and measuring systems such as the Sarin DiaExpert (shown here with DiaMension hardware). Courtesy of Sarin Inc.





Figure 16. During the 1980s, Japanese retailers and diamond brokers began using a variety of specialized viewing devices (typically modified loupes) to demonstrate a diamond's optical symmetry. Over the following decade, some of these devices were adopted by manufacturers and retailers in the U.S. as American consumers became more concerned with cut quality. The EightStar Firescope shown here uses a red reflector in the eyepiece to determine which facets are returning light to the viewer's eyes (inset). Inset photo by Jonathan Weingarten.

## DIAMOND CUT

The preference for well-made diamonds that Japanese consumers developed during the late 1980s was spurred in large part by the introduction of specially made viewers in retail shops. These viewers displayed a round brilliant diamond's optical symmetry in the form of a "hearts and arrows" pattern created by the reflection of the facets (Miller, 1996; figure 16).

The Japanese example began migrating to the U.S. during the 1990s, as American consumers learned more about diamonds, including the fact that appearance depended as much on cut as on other quality factors. A spring 1997 survey by *JCK* and *New York Diamonds* noted that 15% of retail jewelers—mainly those concentrated at the upper end of the market—said their clients were willing to pay a premium for a "well-made diamond" (Shor, 1997a). Five years earlier, that percentage had been negligible. Also in 1997, Lazare Kaplan International (LKI), which had long based its market niche on "ideal cuts," reported a 50% increase in polished diamond sales (Shor, 1997a).

The following year, GIA published the initial results of its extensive research project on diamond

cut, noting that many sets of proportions could result in an attractively cut round brilliant diamond (Hemphill et al., 1998). As the study continued, two additional articles chronicled its findings (Reinitz et al., 2001; Moses et al., 2004). The last of these reaffirmed the original conclusion and provided the scientific foundation for a cut grade based on extensive computer modeling and human observations. The results of the 15-year study also showed that a single cut grading system could accommodate various international preferences.

In 1996, the newly created American Gem Society Laboratories (AGSL) began offering cut grades on diamond reports derived from AGS's then 30-year-old 0–10 system (zero being the best). This development had an immediate effect on Israeli diamond manufacturers who, in producing goods for quality-oriented American retailers, could program AGS's "0" cut-grade parameters into their computerized rough-evaluation machines and manufacture such diamonds automatically (Shor, 1997a).

The growing emphasis on cut gave rise to a new group of entrepreneurs who developed a market niche for diamonds with very high optical symmetry. In addition, diamond manufacturers, often in partnership with retailers, created new cut styles or modifications of existing styles to provide distinction in the retail marketplace and avoid the commoditization of traditional cuts inherent in the diamond price lists and Internet selling.

By 2004, there were at least 101 proprietary diamond cuts competing for attention in the marketplace, only 13 of which had existed prior to 1995 (Overton, 2002, 2004a). Several DTC sightholders, such as Schachter-Namdar (Leo cut) and Rosy Blue (Cento cut), have used such proprietary cuts as an integral part of DTC-promulgated marketing and branding programs that were designed to increase demand and reduce discounting of diamond jewelry at retail.

## CONSUMER DEMAND

Consumer demand for diamonds stagnated through much of the 1990s, even registering small yearly declines between 1993 and 1998 (Katz, 2005), because of growing competition from other luxury products and economic problems in several key consumer markets. Demand rose sharply in U.S. dollar terms after 2001, though some analysts maintain that higher sales figures have stemmed more from price increases than actual volume.



While sales in the U.S., the world's largest diamond-consuming market, remained relatively steady, the aggressive entry of discount merchandisers into diamond jewelry during the 1980s put pressure on traditional wholesalers because the large retailers bypassed them to purchase directly from diamond-cutting centers. These retailers used their volume buying ability to wrest control of diamond prices from manufacturers and dealers (Pearson, 1998), thus creating a profit-margin squeeze that has not abated. The relentless discounting by these retailers and, later, major retail jewelry chains, exerted further downward pressure on retail diamond prices. By 2003, the profit squeeze had halved industry margins to 7–8%, prompting concern from leading industry bankers (Gross, 2003). This stagnation of sales in the 1990s contributed to De Beers's decision to embark on a major recasting of its sales and distribution procedures.

**Boom and Bust in Asia.** Extremes in the Asian markets also played a critical role in pushing De Beers to recast its traditional role as market buffer. Sales of diamond jewelry in the U.S. and Japan (the two biggest markets, consuming nearly two-thirds of all diamond jewelry) ran nearly even from 1988 until the mid-1990s. However, when economic stagnation took hold in Japan in the early 1990s, jewelry sales declined abruptly. As one indication, 79% of Japanese brides received diamond engagement rings in 1995, but only 64% two years later. By 1998, Japan's share of the world market for diamond jewelry had shrunk to approximately 20% (Ralfe, 1999).

Elsewhere in Asia, economic growth in emerging markets such as Korea, Thailand, the Philippines, Malaysia, and China took off in the early 1990s. This caused a dramatic rise in regional diamond jewelry sales, from negligible in 1980 to nearly 7% of world volume by 1995. South Korea, in particular, saw a boom in diamond jewelry consumption, despite various luxury taxes that added more than 50% to the purchase price (Shor, 1997c). Sales of diamond jewelry there reached an estimated \$1 billion in 1996, fourth in the world, up from near zero in 1988, when the country first allowed diamond imports. Sales of diamond jewelry in Thailand reached the half-billion-dollar mark in 1995, and De Beers's market watchers were closely monitoring rising diamond sales in the Philippines and Malaysia. Nevertheless, these markets could not compensate for the decline in Japanese demand.

*The Asian Collapse.* The boom in many Asian nations ended abruptly in 1997, causing an oversupply of diamond inventories (Pearson, 2004). A confluence of forces led to a sharp decline in the region's economy. Several large corporations in Indonesia and Thailand defaulted on loans, setting off runs on those countries' stock markets. Japanese banks, which had been heavily invested in that region, were too preoccupied with troublesome loans in their domestic market to address these problems. Within three months, the currencies of Thailand, Indonesia, and several other Asian nations fell to half or even less of their former values. Shortly afterward, South Korea, mired in its own corporate scandals, saw its currency collapse. Indeed, South Korean consumers began a massive diamond "sell-back" campaign to aid their government, which could no longer meet its international obligations. The International Monetary Fund loaned the country funds to stave off bankruptcy. (A rapprochement between China's government and Hong Kong's business leaders forestalled a crisis in confidence prior to that former British colony's change in government, which occurred July 1 of that year; thus, the problems in other Asian markets had little effect on Hong Kong's diamond industry.)

Diamond sales in the region virtually halted because diamonds, purchased from De Beers's CSO in U.S. dollars, had suddenly become price prohibitive in most of Asia. Retailers, wholesalers, and consumers began a massive unloading of diamonds, many of which were shifted to the U.S. market. Between 1996 and 1998, world diamond jewelry sales fell from \$52 billion to \$48 billion—despite a \$3.2 billion increase in U.S. sales during that period (De Beers Consolidated Mines, 1999).

De Beers reacted quickly by removing so-called "Asian" goods (high clarity, medium color) from its sights in mid-1997, then cutting rough diamond sales by 25% the following year (De Beers Consolidated Mines, 1998). The impact of the Asian collapse and the CSO's cutback on sales left De Beers with a stockpile that, at the end of 1999, stood at a book value of \$4.8 billion—not including the large stocks held by Debswana (Ralfe, 1999). This growing stockpile was Asia's contribution to the company's drastic reorganization in 2000 (described below).

*New Asian and Middle Eastern Markets.* The opening of the new millennium saw a major shift in diamond demand. This helped diamond jewelry sales

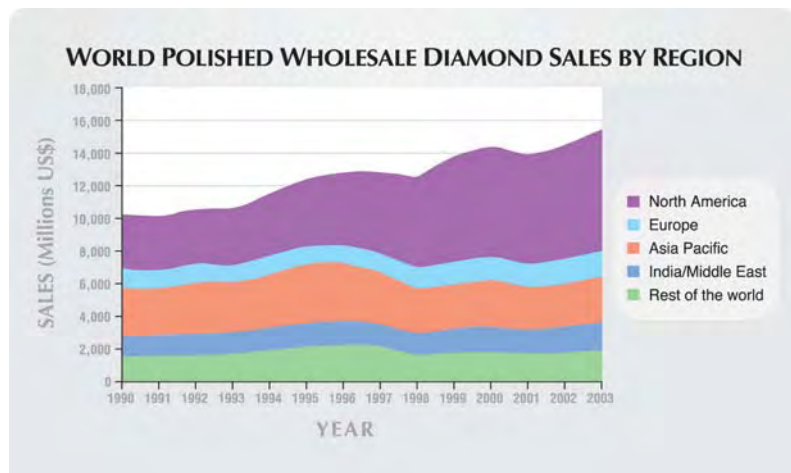


Figure 17. As can be seen from this graph, the North American (primarily U.S.) market has been the main source of growth in world diamond sales since 1990. The United States accounts for nearly half of worldwide diamond jewelry sales. (Source: DTC.)

achieve strong growth worldwide in 2003 (+5.9% to \$59 billion) and 2004 (+8.5% to \$62 billion). U.S. demand for diamond jewelry (\$31.5 billion in 2004) still accounts for nearly half the world's market share (as well as nearly half of world sales of loose diamonds; see figure 17). Nevertheless, in 2004 the consumer market in India grew by 19% to \$1.3 billion, in China by 11% to \$1.5 billion, and in the Persian Gulf (Dubai, Saudi Arabia, Bahrain, etc.) by 14% to \$1.3 billion (Kendall, 2005). Future continued strong growth of these emerging consumer markets could exacerbate shortages of higher-quality polished diamonds and force a rapid increase in prices to U.S. buyers (Singer, 2005).

**Television Shopping and the Internet Fuel a U.S. Boom.** As the millennium approached, the U.S. stock market had begun cresting on the wave of the "dot-com" boom. New avenues of retailing—TV shopping and, much more importantly, e-commerce—were transforming the diamond jewelry landscape.

*Television Shopping.* Electronic retailing began with TV shopping during the 1980s. By 1988, two firms—QVC of West Chester, Pennsylvania and Home Shopping Network of St. Petersburg, Florida—had recorded combined yearly sales of \$2.5 billion in all merchandise categories. Most of the jewelry tended to be lower-priced "impulse" pieces, averaging about \$100 ("The invasion...", 1988). Because of its niche at lower price points and emphasis on "show and tell" visual appeal, TV shopping tended to focus on colored gemstones and gold, with diamonds primarily as accent stones. By 2002, sales of jewelry at QVC had doubled to more than \$1 billion, nearly 42% of total company sales.

HSN sold an estimated \$400 million in jewelry (about 24% of its total sales), while ShopNBC noted sales of approximately \$380 million (Beres, 2004). Jewelry Television by ACN, headquartered in Knoxville, Tennessee, reported that its sales grew from \$5.2 million in 1997 to \$250 million in 2003. The company said its primary customers were people who feel intimidated by the traditional jewelry shopping experience (Gomelsky, 2004a).

*The Internet.* By the end of the 1990s, the Internet had become a significant outlet for diamonds and diamond jewelry, as well as a major source of consumer information about diamonds. Unlike television, which had a visual emphasis that favored large, popularly priced colored stone pieces, the Internet allowed diamond shoppers to easily compare prices of all sizes of stones with grading reports. Internet jewelry sales jumped from about \$38 million in 1997 to \$207 million the following year. Although a minute percentage of the sales reported by traditional storefront jewelers in the U.S. (\$22.4 billion in 1997), the totals were rising rapidly (Diamond, 1999).

The year 1999 saw a number of large-scale start-up jewelry "e-tailing" operations that drew on multi-million-dollar venture capital loans to begin on-line jewelry sales. Shop.org reported that retail sales in all categories via the Internet totaled \$36 billion in 1999. By 2002, that number had doubled; it then jumped 51% to \$114 billion in 2003 (National Retail Federation, 2004).

Despite this extraordinary growth in e-tailing, most of the early on-line jewelry operations failed or were absorbed by stronger competitors. High fixed costs of fulfillment operations, thin sales margins, and a still relatively small customer base made prof-



itable operations difficult. As a result, venture capital firms and banks declined to continue financing many dot-coms. However, several—including Mondera, Blue Nile and Diamonds.com—did survive.

When Blue Nile, headquartered in Seattle, Washington, went public on the NASDAQ stock exchange in May 2004, the company reported a nearly 10-fold increase in sales from its first year in business (\$14 million in 1999) to \$128.9 million in 2003. In a *USA Today* profile (Acohido, 2003), founder Mark Vadon said Blue Nile's growth rested in selling diamonds with as low a margin as possible, marketing to men, and providing consumer education to make the buyer feel comfortable. Blue Nile claims to offer prices between 20% and 40% lower than chain stores, depending on the product (Rapaport, 2004a).

Amazon, the on-line book and music seller, established a jewelry site oriented toward diamonds in 2004. Founder and CEO Jeffrey Bezos said that Amazon would apply the same strategy to jewelry as it used for other categories: to deeply discount products, drive volume, and provide a wide selection (Bezos, 2004).

Online jewelry sales have grown strongly because the business takes advantage of the Internet's initial promise—less overhead, lower prices, and larger selection. The average gross profit margin for online jewelers in 2003 was 23% compared to more than 45% for store-based retailers (Wingfield, 2004). That same year, retailing consultant comScore Networks estimated consumers spent between \$800 million and \$1 billion on jewelry products online (Rapaport, 2004a). The on-line auction site, eBay Inc., reported that sellers auctioned \$1.7 billion worth of watches and jewelry in 2004. A survey conducted by investment firm Goldman Sachs noted that on-line jewelry sales totaled nearly \$2 billion during 2004 and showed the highest sales growth, 113%, of any retail category. For diamond jewelry specifically, one analyst claimed that the Internet represented approximately 2% of total U.S. sales by 2004 (K. Gassman, pers. comm., 2005).

The growing number of diamond dealers and wholesalers who began selling direct to the public via the Internet prompted complaints from retailers that the competition forced a decline in their profit margins for diamonds (Gomelsky, 2004b). One high-end jeweler who had resisted discounts said he finally relented in the wake of intense competition from the Internet (M. Moeller, pers. comm., 2005). Figures from the 2004 Jewelers of America *Cost of Doing Business Survey* bear him out: The average

retailer's gross margin on loose diamonds declined 6.5% (to 39.7%) in 2003.

#### **Auction Houses Provide New Retail Competition.**

During the 1990s, the media drawing power and access to top gem dealers enjoyed by the major auction houses resulted in their becoming important outlets for diamonds and diamond jewelry. By 1996, the combined jewelry sales for Christie's and Sotheby's, who together held a 95% share of the world auction jewelry market, totaled \$500 million (Shor et al., 1997). This represented a five-fold increase over 1986.

The explosive growth of auction sales can be traced back to the decisions by both houses in the late 1980s to branch out from estates and sell newly manufactured goods. By the mid-1990s, one-third of auction offerings, including a majority of large diamonds and major diamond jewelry pieces, were consigned by dealers and manufacturers (Shor et al., 1997), and approximately half their buyers were now private clients, not dealers. Auction house executives and dealers saw, in the words of one, "more 50-carat-plus diamonds changing hands in the past half-decade than all [the years] since Tavernier began cataloguing them in the late 17th century" (Shor, 1998b, p. 42).

There were several reasons for this sudden influx of very large diamonds (figure 18). First, De Beers and other mining companies refined their ore-pro-

*Figure 18. A number of very large diamonds appeared on the marketplace, many at auction, during the mid-1990s. This 100.2 ct emerald cut is near colorless (I) and internally flawless. Courtesy of The Steinmetz Group; photo by Harold & Erica Van Pelt.*



## Box A: COLORED DIAMONDS

Colored diamonds remained largely unknown to most consumers until the 1980s (King, 2003). The publicity surrounding a number of colored diamonds sold at auction (e.g., the Hancock Red in 1987) and, in the early 1990s, Argyle Diamonds' multi-million-dollar advertising campaign for "champagne" and "cognac" diamonds created a growing consumer awareness of these goods.

The goal of Argyle's promotions was to build demand—and prices—for brown diamonds, virtually unknown to consumers at the time. The mine also produced approximately 30,000 to 40,000 carats of predominantly melee-size pink diamonds each year (Even-Zohar, 2002), making it the first consistent source of pink diamonds in the marketplace. Beginning in 1985, every year or so the company selected approximately 50 carats of the highest qualities generally larger than 0.3 ct, quite often colored a distinctive strong purplish pink, for a well-publicized tender sale in Geneva. Not only have these tender sales netted several million dollars in revenue (the company does not officially disclose totals for these sales; Shigley et al., 2001), but they also have generated considerable publicity for colored diamonds (King, 2003).

While the campaign for brown diamonds was aimed at the American mass market, the presence of yellows, blues, and pinks in most major jewelry auctions helped create demand for these colors among Asian buyers (King, 2003). The increased trade in, and awareness of, colored diamonds prompted GIA to update its colored diamond grading system, announced in 1994, subdividing the higher end of the quality ranges into new categories.

Innovations in diamond cutting during the 1970s and 1980s helped maximize face-up color appearance. One effect of these developments allowed "cape" diamonds near the "Z" end of GIA's D-to-Z color scale to be polished into attractive diamonds with noticeable face-up color, frequently placing them in the fancy range. The Radiant cut, patented in 1977, was adapted to yellow diamonds because it emphasized face-up color, allowing manufacturers to improve the color grades of diamonds that appeared light yellow in traditional cuts (King, et al., 2005).

Demand and prices for all types of colored diamonds fell sharply in the late 1990s following the Asian economic collapse, and the number of important colored diamonds offered at auction plummeted. By 2002, however, as the Asian market rebounded, demand for colored diamonds, yellows and pinks in particular, was up again, fueled by celebrities such as

Jennifer Lopez and Whoopie Goldberg and the "bling-bling" (large, costly jewelry worn by celebrities) fad. Colored diamonds had finally become ingrained in the consumer consciousness (King, 2003; figure A-1). One key indicator is that requests for natural-color colored diamond grading services at GIA increased 68% between 1998 and 2003. This popularity led a group of prominent manufacturers to form the Natural Colored Diamond Association in 2004. The group helped feature natural-color colored diamonds in various fashion shows and at the 2004 Academy Awards (NCDia, 2004).



*Figure A-1. Before the late 1980s, colored diamonds were viewed as little more than rare curiosities—such as the Hope diamond—by most consumers. Since then, increased availability and greater popularity among celebrities have helped colored diamonds become an important segment of the market. This collection of dramatic pink and yellow diamond jewelry illustrates some of the design possibilities these gems provide. The center stones in the rings are 0.41 ct (pink) and 0.22 ct (yellow); the eternity band is set with 13 Carré-cut yellow (2.73 ct) and 143 pink (1.15) diamonds. Courtesy of Alan Friedman Co.; photo © Harold & Erica Van Pelt and GIA.*



cessing equipment to reduce the possibility of crushing these large stones (Shor, 1997a). Second, soaring auction prices prompted the administrators of Russia's Gokhran to sell a number of the 10-plus ct rough diamonds that had previously been prohibited from export (Shor, 1998b).

However, the boom in very large diamonds ended in 1997. The small coterie of dealers who purchased million-dollar-plus stones balked at prices that had risen 40–50% in only a few years. For example, a 101 ct D-flawless heart shape offered at Christie's that year failed to bring its reserve of approximately \$12 million. In addition, many Asian buyers stopped participating after the economies of their countries began declining. Auction executives claimed the market, very limited to begin with, had become saturated (Shor, 1997a). The houses soon shifted their emphasis to signed jewelry, pieces from Cartier, Harry Winston, and Van Cleef & Arpels, in particular. Nevertheless, 49 diamonds over 50 ct—35 colorless, 14 colored—were sold at Christie's and Sotheby's auctions between 1990 and 2004 (F. Curiel, pers. comm., 2004).

Combined jewelry sales by the two dominant auction houses remained fairly constant at about \$375 million yearly between 2000 and 2004 (F. Curiel, pers. comm., 2005). The increasing numbers of fine colored diamonds helped reinvigorate the market over the last few years (Box A).

## TREATMENTS

The use of various methods to enhance the color and/or clarity of colorless to near-colorless diamonds is one of the most important developments of the last 15 years. Until the late 1980s, there were virtually no significant treatments for near-colorless diamonds. The 1990s and beyond brought new, highly controversial diamond treatments—some of which, unlike most earlier gem enhancements, presented considerable identification challenges for gemologists. The filling of fractures in diamonds with a lead-based glass to improve the apparent clarity had been introduced in the late 1980s (see, e.g., Koivula et al., 1989). Because retailers were not accustomed to checking diamonds for treatment, many of these filled stones entered the marketplace without disclosure, with tragic results in at least one case (see, e.g., Overton, 2004b). Yet fracture filling was, and continues to be, readily identifiable with magnification.

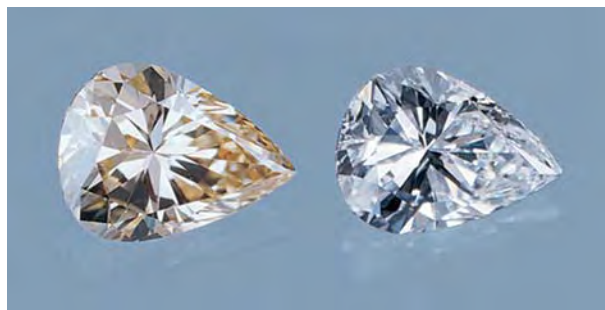
In the 1990s, a significant controversy developed around an older treatment: laser drilling to remove

dark inclusions. When the Federal Trade Commission adopted its revised Guides for the Jewelry Industry in 1996, it did not require disclosure of laser drilling. The Diamond Manufacturers and Importers Association (DMIA), a New York trade organization, argued that the process did not require disclosure because "it is irreversible, does not add a foreign substance, [and] is readily detectable with a loupe" (Shor, 1996b). The organization also noted that the GIA Gem Trade Laboratory, which does not grade diamonds infused with a foreign substance, will grade lasered diamonds (with a notation of the treatment on the report).

The FTC came down on the side of the diamond industry and ruled that permanent, irreversible treatments such as laser drilling did not have to be disclosed to the consumer. This prompted protests from a number of retailer and consumer organizations. Immediately after the ruling, the DMIA reversed its position, fearing a consumer backlash, and lobbied forcefully for a change in the Guides ("FTC...", 1997). The industry, through the World Federation of Diamond Bourses and the International Diamond Manufacturers Association, then adopted a disclosure requirement.

The issue of disclosure of permanent, nonreversible treatments surfaced even more strongly in 1999, when LKI subsidiary Pegasus Overseas Ltd. and General Electric Co. jointly announced they would be marketing diamonds whose color had been enhanced by a high pressure/high temperature (HPHT) process (figure 19) that would "be

*Figure 19. Processing of diamonds with high pressure and high temperature can produce significant changes in color appearance, as with this 0.61 ct pear shape (Fancy Light brown before processing, left; D-color after, right). The introduction of such treatment methods in the late 1990s created heated controversy in the diamond industry. Composite photo by Phillip Hitz, courtesy of the Gübelin Gem Lab.*



indistinguishable" from natural-color diamonds by standard gem-testing techniques (see, e.g., Moses et al., 1999). The announcement touched off waves of protests. A survey by the *Rapaport Diamond Report* asked the question, "If you have an undetectable treatment, is there an obligation to disclose this treatment to the wholesaler, supplier, retailer, and consumer?" Of 323 responses, 280 answered "yes" ("Burning up the wires," 1999).

GIA president William E. Boyajian echoed the prevailing industry sentiment: "If diamonds are treated in any way, then the trade has a right to know—and ultimately so does the consumer. The integrity of the industry is at stake" ("Confidentiality agreement...", 1999, p. 21). De Beers added to the controversy when Gary Ralfe announced at the WFDB Presidents Meeting in Moscow that year that the company had known about the potential for such a treatment for more than 20 years, and had consequently kept type IIa diamonds (the type potentially treatable to colorless/near-colorless by HPHT) out of its sightboxes. After the nature of the process was revealed, a number of other treaters—not all of whom disclosed their activities—began producing both colorless and colored diamonds by HPHT processes. The diamond grading labs, including GIA, noted that they could identify the vast majority of treated diamonds (GIA Gem Trade Laboratory, 2003), but some stones remained a challenge.

## SYNTHETICS

Although Sumitomo Corp. of Japan introduced jewelry-sized gem-quality synthetic diamonds in the mid-1980s, the company focused their efforts on industrial applications. Gem-quality synthetics were also produced, on an experimental basis, by both De Beers and facilities in the former Soviet Union. However, no producer offered synthetics on a commercial scale until 2003, when Gemesis Corp. of Sarasota, Florida, announced that it would market a line of yellow synthetic diamonds created by the HPHT process, using a refinement of Russian technology. Gemesis targeted retailers, marketing its product at various international trade shows. After an aborted effort in the early 1990s, Chatham Created Gems re-entered the synthetic diamond market in 2004 with a new supplier (Shigley et al., 2004; figure 20). Both organizations are currently partnering with jewelry designers to offer finished jewelry as well as loose gems.

Also in 2003, the Apollo Diamond Corp. of Boston, Massachusetts, announced it had achieved a breakthrough in chemical vapor deposition (CVD) technology that allowed the growth of jewelry-size single-crystal colorless synthetic diamonds (Wang et al., 2003). To date, however, Apollo has not released its CVD product into the gem market.

A potentially more significant source of CVD synthetics emerged from research announced in mid-2005 by the Carnegie Institute in Washington, DC, which claimed it could grow 10 ct, half-inch-thick synthetic diamonds at a rate of 100 micrometers per hour—five times faster than commercial products made using high pressure and high temperature—that did not need HPHT treatment to improve their color, as was the case with most other CVD-grown synthetic diamonds (Hemley, 2005).

Gemesis' marketing plan stirred controversy over its use of the term *cultured* diamonds in place of *synthetic*. Jewelers Vigilance Committee (JVC) executive director Cecilia Gardner said the JVC viewed the term as "insufficient" disclosure (Robinson, 2004). In Europe, a Munich court issued a restraining order against the use of the term by Gemesis' German distributor in 2004. The court ruled that the company could use only two words to describe synthetic diamonds: *synthetic* or *artificial*.

Although colorless synthetic diamonds have received a great deal of press, as of this writing there have been no reports of any commercial production, and the output of fashionable colored synthetics remains fairly small. In addition, all known synthetic diamonds are detectable with the proper gemological tests and equipment (Shigley, 2005). The DTC, however, is looking to the possibility that synthetic diamonds may become a competitive threat in the future by refocusing part of its advertising to stress the beauty and rarity of natural diamonds.

## THE BRANDING REVOLUTION AND SUPPLIER OF CHOICE

**The Branding Revolution.** Unlike the majority of products sold at retail, diamond jewelry traditionally was branded by the retailer: Harry Winston, Tiffany & Co., Cartier, and the thousands of "main street" jewelers whose reputation backed the quality of their products. Yet this was not the case for loose diamonds, especially the standard round brilliant.

Although several firms had specialized in so-called ideal-cut diamonds, it was not until the late





Figure 20. After decades of experimental production, gem-quality synthetic diamonds finally reached commercial viability in the early 2000s. Though long a source of concern to the industry, all can be identified by a well-equipped gemological laboratory. The yellow synthetic diamond in the ring is 0.92 ct; the pink synthetic diamonds in the other ring are 0.38 and 0.40 ct; while the bracelet contains 7.48 ct of yellow synthetic diamonds (apparent sizes vary in this composite photo). Courtesy of Chatham Created Gems.

1990s that significant attempts were made to develop distinctive diamond brands around premium cuts, as manufacturers and retailers alike sought to differentiate themselves in the marketplace. One company, Hearts on Fire, developed a large marketing infrastructure to train retailers and sales associates to demonstrate the claimed differences in appearance between their premium-cut diamonds and commercially cut stones (Shor, 2002). At the same time, a number of diamond manufacturers, as noted above, sought to create brands from newly created fancy or modified brilliant diamond cuts.

In 1998, De Beers brought the branding issue to the forefront when it announced it would develop, in conjunction with sightholders, a special Millennium Diamond campaign, using a proprietary technique to apply a microscopic message to the table of each diamond. Participating retailers would show customers the message via specially purchased viewing devices. The program was designed with a two-fold purpose: to promote diamond jewelry to mark an historic milestone, and to distinguish diamonds marketed via De Beers's clients from those of other suppliers.

While the Millennium Diamond program was geared to a specific event, De Beers's executives prepared a much more sweeping initiative in 2000 that would tie branding to vast changes in the diamond distribution system by promoting strategic partnerships between retailers and diamond manufacturers as well as extensive marketing efforts.

#### **De Beers's Strategic Review and Supplier of Choice.**

The advent of significant competition from other producers, a growing rough diamond stockpile, declining market share, and underperformance of diamonds as a luxury item compared to other products, prompted the executives of De Beers to initiate a total review of its operations in 1999. With Argyle's break from De Beers, Alrosa's growing independence, and the company's failure to win a majority control of Canada's Ekati production, De Beers executives realized they had to recast their operation to adapt to a multi-channel distribution system. This included: reconfiguring the company's diamond advertising to favor its own clients (rather than benefiting other producers); ensuring the integrity of its supply chain to keep out undisclosed treated and synthetic material and conflict diamonds; and ending its "custodial" role, which ultimately had benefited its competitors as much as its clients.

De Beers hired an American management consulting firm, Bain & Co., to review its entire operation and develop a strategic plan to respond to the changes taking place in the diamond world. In 2000, De Beers announced it would implement a new marketing system: "Supplier of Choice" (SOC). Company executives envisioned a diamond market with a "multitude of competing brands" that would serve to drive up consumer demand for the entire sector (Diamond Trading Company, 2000). SOC also included a set of Best Practice Principles, which bound clients to handle only diamonds obtained from legitimate sources, to

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maintain safe work environments, and to strictly disclose all treatments.

The DTC then announced that it would revise its client list on the basis of "objective criteria," which would include clients' participation in downstream marketing activities, their ability to "add value" to the diamond distribution process, the efficiency of their distribution practices, and their adherence to Best Practice Principles.

SOC brought one immediate change in the way the CSO/DTC had marketed its rough to clients. Instead of supplying goods on the basis of client requests for each sight (which were often in excess of their needs), clients now worked with a DTC liaison to determine their requirements, based closely on their actual sales volumes, for a six-month period. Where possible, the DTC would schedule these allocations, called Intentions to Offer (ITO), for that period.

The DTC asked the European Commission to review its SOC initiatives, promising to make any necessary changes. There were two objectives to this move: (1) to forestall criticism and possible legal action from those whose businesses might be affected by SOC, and (2) to provide a legal precedent that would help remove the anti-trust sanctions that had barred the company from operating in the U.S. since 1944.

After requiring some modifications, the EC granted its approval to SOC in late December 2002. On June 1 of the following year, the DTC announced its new client list, pared by one-third to 84 companies. A number of those dropped included some of the best-known operations in the industry. The announcement brought sharp criticism from executives of diamond bourses in Antwerp and Israel, which lost numerous sightholders, as well as from the WFDB, which represents primarily smaller dealers. The latter enacted a resolution in 2003, stating that SOC had created a situation in which "the rough market has become concentrated in fewer hands, seriously threatening the business structure of the established wholesale diamond sector" (Katz, 2003).

Three companies dropped from the DTC's client list—IDH Diamonds NV and A. Spira, both of Antwerp, and W. B. David & Co. Inc. of New York—each separately filed suit against the DTC. Gareth Penny, DTC executive director of sales and marketing, defended the trading company's actions, saying that cuts were concentrated among those dealing in the larger sizes and higher qualities

because, given the DTC's decline in market share, it could no longer provide adequate supplies of such goods (Shor, 2004). In response to the torrent of criticism over its cuts in client rolls, Gareth Penny announced that the DTC would supply \$500 million of rough diamonds to non-sightholder diamond manufacturers through its subsidiary, Diamdel (Katz, 2004a).

In June 2005, the DTC announced it would add 11 new clients beginning in January 2006 and review its client rolls every 30 months thereafter. Nevertheless, the following month, the Belgian Association of Dealers, Importers, Exporters of Polished Diamonds filed a complaint with the EC alleging that the DTC had abused its dominant position and artificially limited the availability of diamonds in the market (Belgian Association..., 2005).

**De Beers's Retail Venture.** De Beers also underwent two other dramatic changes. Early in 2001, the company announced it would "unlock" the brand value of the De Beers name in a joint retail venture with the French luxury firm Moët Hennessy Louis Vuitton (LVMH). It changed the name of Debid, its industrial diamond division, to Element Six, and reserved the De Beers name, outside its home in South Africa, for the retail venture.

The company opened its first retail store on London's New Bond Street, amid a row of other top luxury jewelers, in December 2002. The following September, De Beers LV opened three boutiques in Tokyo, set inside major department stores. On the eve of the opening of its New York store in June 2005, De Beers LV indicated plans to have 20 stores in the U.S. within five years, and eventually 150 retail operations worldwide (Robinson, 2005b).

Industry criticism of the De Beers retail venture flared up after the announcement of the new sightholder list. Because most of the cuts were concentrated among clients who handled larger diamonds, some accused the firm of manipulating supplies to further its own retail ventures (Even-Zohar, 2003).

**Privatization of De Beers.** The second major change was De Beers's announcement in 2001 that it would convert from a publicly traded corporation to a private company. When the transaction was finished in June of that year, the ownership of the firm rested with three groups: The Oppenheimer family investment firm Central Holdings Ltd. and Anglo American Group., each with 45%, and Debswana,



the 50-50 joint venture with the government of Botswana, with the remaining 10%. Most of the \$18.7 billion deal was financed by sales of Anglo-American stock and other assets; \$3.35 billion of the transaction came from loans.

The conversion of De Beers into a private company turned the firm, in the short term, from one with ready cash reserves to one carrying a multi-billion-dollar debt. De Beers made a series of internal cuts and continued selling its stockpile, so that by mid-2004 the company had reduced debt to \$1.76 billion and its stocks to less than \$1 billion—nearly working levels. However, the huge expense involved in the privatization reduced the company's ability to influence prices (by withholding stocks) and national policies (such as with the \$1 billion loan to the Soviets in 1991).

De Beers's executives also moved to resolve a decade-old charge that it had conspired with General Electric Co. to fix prices of industrial synthetic diamonds. A federal court had dismissed the charges against GE, but since De Beers never answered the indictment, the charges against it remained active. In July 2004, the company pleaded guilty to an unanswered price-fixing charge and paid a \$10 million fine. This was the first step of a strategy to remove the legal barriers that have prevented the firm from operating directly in the U.S.

**Other Strategic Partners.** Outside of the DTC's purview, a number of vertical-integration deals have occurred between producers seeking stable, reliable outlets for their diamonds and retailers desiring a reliable source of supply. The case of Aber Resources and Tiffany & Co. offers an interesting example.

During the long development period of Canada's Diavik mine, Tiffany & Co. acquired a 25% stake in the mine's junior partner, Aber Resources. The transaction would provide the retailer with direct access to Diavik's production at advantageous prices when the mine came on stream. However, in March 2004, Aber Resources itself acquired a controlling interest in Harry Winston Co. Aber president Robert Gannicott explained his rationale for acquiring Winston: Next to mining, retailing was the most profitable segment of the diamond business. In addition, the stake in Winston would allow the company to remain in business after the mine closed (Gannicott, 2004).

Tiffany ended its equity relationship with Aber in the fall of that year, though the mining company

continues to supply it with \$50 million of rough diamonds yearly. Tiffany then moved to further assure its diamond supplies by signing a memorandum of understanding with a smaller Canadian producer, Tahera Diamonds, to buy the entire three-million-carat diamond production anticipated over its projected nine-year life. Tahera is developing the Jericho mine in Nunavut, which is projected to begin production in 2006.

Although the concept of retailers having direct access to mine production or a DTC sight is not a new one (Zale Corp. was a sightholder in the 1970s and 1980s), the number of these alliances, tied as they are to the luxury market where the greatest scarcities lie, could result in diminished supplies of such diamonds reaching the open market, extending the competitive reach and domination of the industry's largest players.

## THE RISE OF INDIA IN MANUFACTURING

When the DTC announced its new, greatly reduced client list in 2003, India's industry actually had a net gain of five sightholders, while the other three "traditional" centers lost a third or more of their (*Diamond Trading Company Sightholders*, 2004). This event, perhaps more than any other, demonstrated how the balance of the world's diamond manufacturing industry had shifted to that country (see also table 2 and figure 21).

**TABLE 2.** Share of DTC rough diamond sales direct to India, 1990–2004 (in millions of US\$).<sup>a</sup>

Year	Total DTC sales	India's share	% of DTC sales
1990	4,167	638	15
1991	3,927	678	17
1992	3,417	566	17
1993	4,366	706	16
1994	4,250	690	16
1995	4,531	747	16
1996	4,834	677	14
1997	4,640	618	13
1998	3,345	483	14
1999	5,240	777	15
2000	5,670	995	18
2001	4,454	989	22
2002	5,154	1,127	22
2003	5,518	1,469	27
2004	5,695	1,608	28

<sup>a</sup> Source: "DTC sale..." (2005). Note that this chart does not include the substantial amounts of DTC rough that are transhipped through Antwerp.

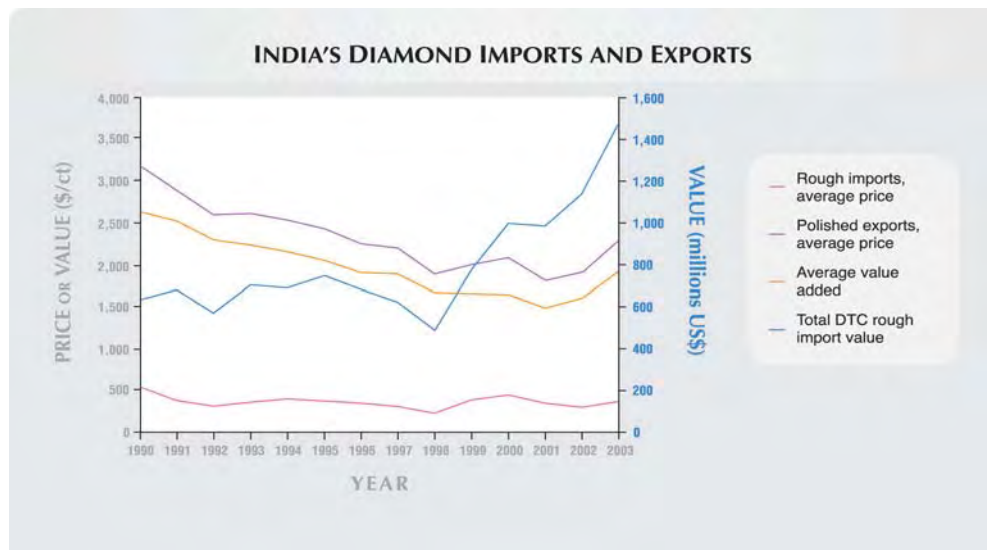


Figure 21. Though the average per-carat value of rough imported to India remained relatively constant from 1990 to 2003, the per-carat value of polished exports fell during much of this period—until the advent of De Beers's Supplier of Choice program in 2000–01, when the value of DTC rough imports rose sharply. (Sources: "Average price...", 2005; "DTC sale...", 2005.)

While Antwerp remains an important trading hub for rough diamonds (45% of the DTC's sales passed through the city in 2002; Even-Zohar, 2002), its role as a diamond manufacturing center has diminished sharply. An estimated 2,000 workers are currently employed full-time there in diamond manufacturing, compared to approximately 8,500 in 1984 (Shor, 1984) and 19,000 in 1968 (Even-Zohar, 2002). Manufacturing in Israel has seen similar declines, from a 1970s peak of approximately 13,000 to less than 4,000 in 2002. In both cases, rising labor costs in the face of increasing retail price competition were a key factor, with the implementation of highly automated manufacturing operations further contributing to workforce reductions in Israel (Caspi, 1997).

With a million or more diamond workers, India has become the overwhelmingly dominant force in diamond manufacturing (figure 22). India's trade organization, the Gem and Jewellery Export Promotion Council, reported early in 2004 that 92% of all diamonds in the market were manufactured in India; this is up from 60% in 1990 (Sevdermish et al., 1998). This represented 60% by value, up from 33% in 1990.

The extraordinary growth of India's diamond industry was achieved by capitalizing on a number of events:

- The huge production from the Argyle mine, much of which could not have been cut profitably in any other center
- Increased demand from U.S. mass marketers

for affordably priced diamond jewelry

- Sales of large amounts of Russian "technical" goods from the Kremlin stockpile
- Greater direct access to the American consumer market
- New technology that permitted processing of diamonds much more efficiently and quickly, and with much greater precision

In the early 1990s, many of India's second-generation diamond manufacturing executives began looking beyond the niche of small, lower-quality diamonds on which their industry was originally built. They focused on two areas: finished jewelry and larger, better-quality loose diamonds. Finished jewelry, they believed, would bring higher profit margins than loose goods that were easily price-shopped.

Through its Indo-Argyle Diamond Council, Argyle provided a direct conduit to the lucrative American finished jewelry market. The Council's U.S. marketing consultants, MVI, worked with mass marketers and large retail jewelry chains to determine their needs regarding quality and service. The Council then embarked on a stringent program to bring Indian jewelry manufacturers up to world standards regarding working conditions, employment (including age), and quality of product. De Beers also adopted labor and working-condition standards into its Best Practice Principles, and Argyle adopted them into its Business Excellence Model.

By 2004, the 10th anniversary of Indo-Argyle's founding, top retailers including J.C. Penney, Signet



Group, Zale Corp., and Wal-Mart had established permanent buying offices in Mumbai through the Council's efforts. Beyond Indo-Argyle, Indian firms have established an international presence through De Beers's SOC, including a number of strategic partnerships with U.S. and European companies (Weldon, 2004b).

India's younger generation of diamond manufacturers also saw diamond-processing technology as a means of taking their industry to a higher level in terms of quality and speed of production (S. Doshi, pers. comm., 2004). American and Asian retailers demanded that even "stars" (50 per carat or smaller) be well made and show "life." In the early 1990s, India's production of Argyle goods greatly accelerated following the introduction of a new type of scaife that was impregnated by diamond powder. Argyle material was considered very difficult to work because the crystals were usually distorted and brittle, requiring diamond polishers to constantly monitor every stone and shift the polishing angle in tandem with the grain. Failure to do this often resulted in broken or "burned" diamonds. The diamond-impregnated scaife not only eliminated the need to constantly turn diamonds on the wheel, but it also allowed manufacturers to automate the polishing process.

The maturity of India's diamond-manufacturing industry coincided with the rapid growth of that country's middle class, who have become prolific diamond consumers in their own right. The combination of India's dominance in manufacturing with growing domestic consumer demand has transformed the country into a force that can affect and influence how the industry in the rest of the world does business.

## FUTURE OPPORTUNITIES AND CHALLENGES

The DTC's stated policy of pushing more marketing initiatives to build demand and the luxury image of diamonds will undoubtedly continue to affect the diamond market. Although new mine production will likely meet rising consumer demand in the long run, shortages of rough diamonds in certain size and quality categories will remain for some time. Rough and polished prices may become more volatile because the DTC, Alrosa, Rio Tinto, Debswana, and Namdeb have sold most of their buffer stocks, reducing their ability to mitigate supply shortages and influence prices. In addition, competition between



*Figure 22. Over the past three decades, the center of the diamond-polishing industry has shifted east from Europe and Israel to India. Due in part to low labor costs and a large, well-educated workforce, India has become the world's leader in diamond manufacturing. Over 90% of the diamonds on the market are now cut in India. Shown here is the KARP factory in Jasdán, Gujarat. Photo © H. Goldie & Company.*

producers will make price regulation more difficult (Pearson, 2004).

Supplies of small diamonds, the mainstay of U.S. mass merchandisers, may be greatly reduced if Rio Tinto decides not to redevelop Argyle into an underground mine. While new diamond sources are being developed, principally in Canada, they do not promise the vast yields of smaller goods that Argyle currently produces.

The desires of diamond-producing nations to increase revenue and employment by localizing diamond manufacturing operations will likely raise manufacturing costs, because the majority of these nations have a much higher wage structure than India, while they will accelerate employment decline in higher-wage cutting centers such as Antwerp and Israel.

The balance of the industry will continue to tip toward Asia because much of the growth in consumer demand will likely come from two emerging markets, India and China. Sales of diamond jewelry in the former increased almost three-fold from 1995 to 2003, to Rs 55.968 billion (\$1.287 billion). China has experienced similar growth (Kendall, 2004). The DTC has instituted major consumer advertising programs in both countries to tap into the rapidly improving purchasing power of the middle classes. Growing consumer demand



Figure 23. Despite dramatic changes in the diamond industry, fine diamond jewelry remains an important element of modern fashion, with an ever-increasing array of choices for designers and consumers. Yellow diamond (1.99 ct) ring courtesy of Kathryn Kimmel, GIA; brooch courtesy of Fortunoff; Infinity bracelet by Pascal LaCroix; other items from the GIA Collection. Photo © Harold & Erica Van Pelt and GIA.

in new markets, coupled with increasing sales in mature markets such as the U.S., will continue to keep rough diamond supplies a significant issue (Mehta, 2003).

Although diamond demand has grown rapidly in India and China, these areas still comprise a relatively small share of sales as compared to established consumer nations like the U.S., Japan, and Western Europe. The DTC has noted moderate dollar-value sales growth in these markets, although real increases were much lower when measured against rising polished prices—particularly in carat-plus goods. Indeed, some analysts believe such increases are more the result of DTC price hikes than greater demand (K. Gassman, pers. comm., 2005).

Banks have assumed a much more active role in the diamond industry in recent years, because industry credit requirements more than doubled—

from \$3.9 to \$8.6 billion—between 1995 and 2003, while profit margins have been shrinking, payment cycles have lengthened, and polished inventories of some qualities have been mounting. Banks have expressed concern over rising debt levels and, while stressing their ongoing commitments to the diamond industry, have assumed increasing veto power over deals with retailers or manufacturers who carry excessive memo or payment terms, such as one year (Gross, 2003). All indications are that banks will continue to grow stricter with the diamond industry, while retailers continue to push for increasingly generous terms.

Corporate governance issues will become more ingrained into industry practice through initiatives launched at the close of 2004 and early in 2005. The so-called Early Adopters' Initiative, which developed into the London-based Council for Responsible Jewellery Practices, began in November 2004. Participants in this effort—many of the industry's leading businesses and trade organizations—seek to promulgate a unified code of business practices regarding adherence to the Kimberley Process and PATRIOT Act provisions, fair labor practices, and full disclosure of treatments and synthetics at all distribution levels. In January 2005, De Beers, together with NGOs Global Witness and Partnership Africa Canada, the World Bank, and various governments, launched the Diamond Development Initiative, designed to integrate the diamond production of African *garimpeiros* into the "formal" mining sector. Currently, the Kimberley Process does not take into account the production of the estimated one million diggers in countries such as Angola, the Democratic Republic of the Congo, and Sierra Leone. The conveners of the initiative believe that bringing this production into the formal mining sector, with Kimberley Process accountability, would reap major benefits for the miners, governments, and the diamond industry (O'Ferrall, 2005).

## CONCLUSION

The last 15 years have brought changes to the diamond industry that have affected every part of the pipeline, from mine to retail. As new diamond sources opened up, De Beers's single-channel marketing system, in place since the 1930s, gave way to a multi-channel environment. This required that the company transform itself into a more market-driven business. It also ended its traditional role



of market custodian as it sold its buffer stock of rough diamonds, which profoundly affected diamond manufacturers and dealers downstream. The Supplier of Choice initiative alone represents one of the most sweeping changes in the diamond industry in the past half century.

Civil wars in several producing nations forced the diamond industry to account for the legal legitimacy of the goods it sells, while governments anxious to cut off terrorist financing and money laundering subjected the industry to unprecedented scrutiny. Now, governments of producing nations are placing greater pressure on De Beers and other mining companies to establish "beneficiation" projects to increase local ownership, employment, and revenues.

Jewelry retailers saw new competition, first from auctions, which became a major sales outlet for the extreme top end of the market, and then from the

Internet, which also brought consumers access to a great deal of gemological and market information about diamonds. New diamond cuts and branded diamonds provided an array of new choices for consumers and business opportunities for diamond firms (figure 23), while colored diamonds took center stage in the celebrity fashion world. Gemologists and dealers at all levels were faced with new treatments and the commercial availability of jewelry-quality synthetic diamonds.

The political and structural changes in diamond distribution will likely cause continued realignments within the diamond-manufacturing and trading centers, with resulting pressures on supplies and profits. Through all these changes, sales of diamond jewelry have continued to grow strongly worldwide, promising lucrative opportunities to dealers and retailers with the market knowledge and gemological know-how to take advantage of them.

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# EXPERIMENTAL CVD SYNTHETIC DIAMONDS FROM LIMHP-CNRS, FRANCE

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In the last decade, progress in diamond growth by chemical vapor deposition (CVD) has resulted in significant improvement in the quality of synthetic single crystals. This article reports on the gemological and spectroscopic features of six synthetic type IIa diamonds grown for research purposes at the French Laboratoire d'Ingénierie des Matériaux et des Hautes Pressions (LIMHP-CNRS), and compares their diagnostic features to CVD-grown diamonds from other producers. Three of the six samples were nitrogen doped, whereas the other three were classified as high purity. A number of characteristics that are diagnostic of CVD synthetic diamond were present in the nitrogen-doped crystals, despite an absence of defect-related absorption features in the infrared region. Identification of the high-purity samples was more complicated, but it was still possible based on features in their photoluminescence spectra, their distinctive birefringence, and characteristic luminescence images.

**D**iamond synthesis was first accomplished more than half a century ago, and there have been considerable improvements in quality over the past few years. These achievements are important not only for the potential they offer for producing large quantities of synthetic diamond, but also for the precise control they provide over the type and concentration of defects in the crystals, which is particularly critical for electronics applications. To date, most gem-quality synthetic diamonds have been grown using high-pressure and high-temperature (HPHT) conditions (Shigley et al., 1986, 1987, 1997, 2003, 2004). Recently, however, single-crystal diamond synthesis using the chemical vapor deposition (CVD) method has made great progress and attracted much attention, even in the jewelry industry (see, e.g., Yan et al., 2002; Wang et al., 2003; Martineau et al., 2004; Bates, 2005; Tallaire et al., 2005). Earlier this year, Yan et al. (2005) documented the successful growth of a 5 ct single-crystal CVD synthetic diamond measuring over 1 cm thick. They also predicted that a one-inch cube of single-crystal CVD synthetic diamond (~300 ct) is achievable. The properties of CVD synthetic diamonds are highly variable, due to the rapid devel-

opment of laboratory synthesis techniques. Therefore, the timely characterization of these synthetic diamonds is critical to the gem industry.

In this article, we report on the properties and identification features of several CVD synthetic diamonds that were produced for research purposes at the Laboratoire d'Ingénierie des Matériaux et des Hautes Pressions, a part of the Centre National de la Recherche Scientifique (LIMHP-CNRS) at the Université Paris 13. These products showed some notable differences from those grown by Apollo Diamond Co. that were examined by Wang et al. (2003) and the experimental products studied by Martineau et al. (2004). Nevertheless, these new CVD-grown diamonds can be identified on the basis of certain characteristic gemological and spectroscopic features.

At LIMHP-CNRS, these CVD synthetic diamonds were produced at low pressures (a few hundred millibars) from hydrogen-rich methane mix-

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See end of article for About the Authors and Acknowledgments.  
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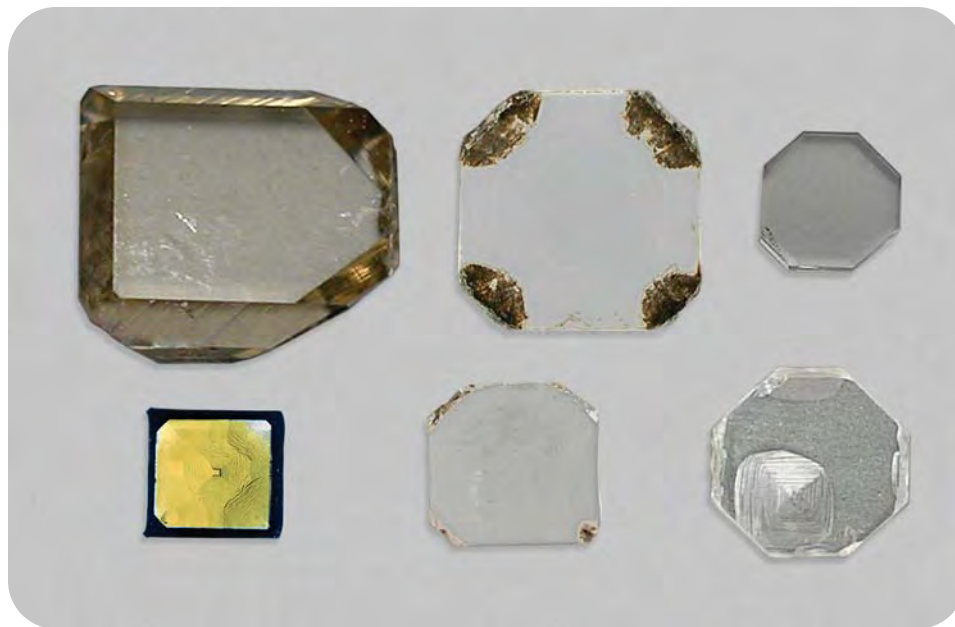


Figure 1. The CVD synthetic diamonds (0.14–0.81 ct) from LIMHP-CNRS show a typical tabular crystal morphology and significant variations in color. Three samples were near colorless, two were light gray, and one was light brown. The three samples in the top row (from left to right: nos. 67404, 66875, and 66669) are nitrogen doped, and the three in the bottom row (from left to right: nos. 66675, 66876, and 67405) are of high purity. Sample no. 66675 appears yellow due to the yellow substrate. Composite of photos by Elizabeth Schrader, Jessica Arditi, and W. Wang.

tures. The use of microwave radiation in the growth chamber facilitated the production of key molecular species involved in diamond growth inside the plasma ball. To grow a monocrystalline diamond crystal, a type Ib {100}-oriented slice of HPHT synthetic diamond was used as a substrate. By choosing optimum growth conditions for the substrate temperature, the methane concentration, and the microwave power density, researchers at LIMHP-CNRS were able to achieve growth rates of tens of micrometers per hour at relatively high quality and purity (Tallaire et al., 2005). These samples were grown solely for research purposes, and although it is technically possible to do so, no crystals thick enough to be faceted were produced. While colorless, light gray, and light brown gem-quality CVD-grown synthetic diamonds are being produced experimentally by LIMHP-CNRS, this group does not intend to make its synthetic diamonds available to the jewelry market.

## MATERIALS AND METHODS

Six specimens produced by LIMHP-CNRS during late 2004 and early 2005, ranging from 0.14 to 0.81 ct, were examined (figure 1). All were studied as-grown, with no secondary treatment. Three of them were intentionally doped with various concentrations of nitrogen during the CVD deposition process in order to improve the growth rates. These samples were labeled nos. 67404, 66875, and 66669 for the very low, low, and moderate doping amounts, respectively. For the other three samples, the growth conditions were chosen to limit the incorporation of

defects into the crystal lattice as much as possible. They are referred to here as nos. 66675, 66876, and 67405. The growth substrates were entirely removed prior to spectroscopic analysis as well as color grading during this study, except for one high-purity sample that had a CVD thickness of only about 0.3 mm (no. 66675). These CVD synthetic diamonds are representative of recent products created at LIMHP-CNRS, which show a significant variation in color and chemical purity.

Gemological and spectroscopic properties of all six samples were collected at the GIA Laboratory in New York. Although GIA does not issue grading reports on synthetic diamonds, for the purpose of this study equivalent color grades were determined by experienced diamond grading staff using the standard conditions and methodology of GIA's color grading system for colored and near-colorless faceted diamonds (see, e.g., King et al., 1994). Note that the color grades of these tabular samples could change after faceting as the optical path length is increased. Internal features were observed with a standard binocular microscope and a variety of lighting techniques. We used a gemological microscope with crossed polarizers to check for anomalous birefringence in all samples. Reactions to UV radiation were checked in a darkened room with a conventional four-watt combination long-wave (365 nm) and short-wave (254 nm) lamp.

Five of the samples also were analyzed at the GIA Laboratory using several spectroscopic techniques. Because the substrate of no. 66675 was not removed, only photoluminescence (PL) spectroscopy was per-

**TABLE 1.** Characteristics of CVD synthetic diamonds from LIMHP-CNRS, France.<sup>a</sup>

Sample no.	Description	N <sub>2</sub> doping during growth	Weight (ct)	Size (mm)	Color	UV fluorescence <sup>b</sup>	Fluorescence in the DiamondView
<b>Nitrogen doped</b>							
67404	Free standing	Very low	0.81	6.55 × 5.96 × 1.64	Light brown	Inert	Orange (with blue phosphorescence)
66875	Free standing	Low	0.41	6.33 × 6.27 × 0.70	Light gray	Inert	Orangy red (with blue at four corners)
66669	Free standing	Medium	0.31	3.99 × 3.87 × 1.42	"G" color	Inert	Orangy red
<b>High purity</b>							
66675	About 0.3 mm thick, over HPHT synthetic diamond substrate	None	0.40	3.88 × 3.86 × 1.87	Near colorless (over yellow substrate)	nd	Green (from the substrate)
66876	Free standing	None	0.14	4.41 × 4.42 × 0.48	Light gray	Inert	Blue
67405	Free standing	None	0.18	4.47 × 4.46 × 0.71	"I" color	Inert	Blue (with blue phosphorescence)

<sup>a</sup> Abbreviation: nd = not determined

<sup>b</sup> Reaction to a standard gemological source of long- and short-wave UV radiation

formed on this sample. To avoid surface contamination, we cleaned the samples thoroughly with acetone in an ultrasonic bath. Low-temperature PL spectra were recorded for all six samples using a Renishaw 1000 Raman microspectrometer with an Ar-ion laser at two different laser excitations: 488.0 nm (for the range 490–950 nm) and 514.5 nm (for the range 517–950 nm). PL spectra in the range 640–1000 nm also were collected using a He-Ne laser (632.8 nm) for the five samples that had their substrate removed. In addition, PL spectra for one sample (no. 67405) were obtained using a diode laser (780.0 nm) for the range 782–1000 nm. Several excitation lasers were used to cover as broad an emission-energy region as possible. The samples were cooled by direct immersion in liquid nitrogen. Up to three scans were accumulated in some cases to achieve a better signal-to-noise ratio.

Infrared absorption spectra were recorded in the mid-IR (6000–400 cm<sup>-1</sup>, 1.0 cm<sup>-1</sup> resolution) and near-IR (up to 11000 cm<sup>-1</sup>, 4.0 cm<sup>-1</sup> resolution) regions at room temperature with a Thermo-Nicolet Nexus 670 Fourier-transform infrared spectrometer equipped with KBr and quartz beam splitters. A 6× beam condenser focused the incident beam on the sample, and a total of 1,024 scans (per spectrum) were collected to improve the signal-to-noise ratio.

UV-Vis-NIR absorption spectra were recorded

with a Thermo-Spectronic Unicam UV500 spectrophotometer over the range 250–850 nm with a sampling interval of 0.1 nm. The samples were mounted in a cryogenic cell and cooled using liquid nitrogen.

All the samples also were examined using a Diamond Trading Company (DTC) DiamondView deep-ultraviolet (<230 nm) luminescence imaging system (Welbourn et al., 1996).

## RESULTS AND DISCUSSION

**Gemological Features.** Table 1 details the gemological and spectroscopic properties of the LIMHP-CNRS synthetic diamonds. All six crystals exhibited the tabular morphology typical of monocrystalline CVD products, each with a large cubic (100) crystal face. Three of the samples were near colorless, two were light gray, and one was light brown (again, see figure 1). The colors of these samples are very different from those of the Apollo CVD synthetic diamonds, most of which showed brown colors of varying saturation (Wang et al., 2003). The one brown sample in this study (no. 67404) showed an even color distribution, except when viewed perpendicular to the growth direction; in this orientation a distinct zone of dark brown color was visible (figure 2). This very narrow color zone extended parallel to the large (100) face



Major absorption features		Photoluminescence features
Infrared	UV-Vis-NIR	
6856, 3323, 3124, 2924, 2807 cm <sup>-1</sup>	Increase in absorption to high-energy side; 737 nm	503.5, 563.3, 596/597, 575, 637, 737, 766.1, 840.7 nm
No defect-related features	No features	503.5, 575, 596/597, 637, 699, 737 nm
No defect-related features	No features	503.5, 540.7, 563.3, 575, 596/597, 637, 737 nm
nd	nd	503.2, 503.5, 575, 596/597, 637, 699, 737 nm
No defect-related features	No features	737 nm
No defect-related features	Broad band at ~261 nm	737, 953 nm

through the entire CVD overgrowth, and was the main cause of the light brown body color. Brown zoning also was observed in the Apollo CVD synthetic diamonds (Wang et al., 2003); it may be caused by concentrated deposition of non-diamond carbon as a result of temperature fluctuations during growth. The presence of non-diamond carbon in the brown sample in this study was revealed by Raman bands at around 1450 cm<sup>-1</sup>; such bands in CVD-grown diamond are much broader than the Raman peak at 1332 cm<sup>-1</sup> that is intrinsic to diamond.

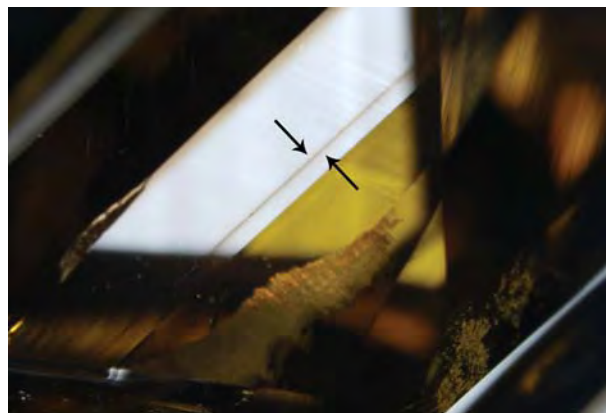
Layers of different colors also have been observed in many CVD products from Element Six. According to Martineau et al. (2004), layers with various brown colors were most common, with blue layers observed in samples doped with boron.

The CVD-grown diamonds were of high clarity. However, a few notable internal features were present. In sample no. 66875, graphite inclusions, identified by Raman spectroscopy, were well developed in the four corners and arranged in the {111} orientation along many small fractures. Although the mechanism responsible for the formation of graphite in these crystals is unclear, it is well known that nitrogen incorporates and degrades the {111} faces preferentially, leading to a higher content of non-diamond carbon. In addition, many pin-points were present in sample no. 66669.

The main {100} growth surface of the nitrogen-doped samples invariably showed sequences of micro-steps with relatively flat “terrace” regions separated by inclined “risers.” This phenomenon is known as step-bunching, and the corresponding features have been referred to as growth steps (de Theije et al., 2000; Martineau et al., 2004). It was observed on all the nitrogen-doped samples (figure 3), and also on portions of high-purity sample 66675 (figure 4). But in the latter case, since no nitrogen was intentionally added, the higher methane concentration present during growth was probably responsible for the surface growth features observed.

Anomalous birefringence, caused by residual internal strain, is a useful feature for the identification of CVD synthetic diamond (see, e.g., Wang et al., 2003; Martineau et al., 2004). Similar to many of the Apollo products examined, the CVD synthetic diamond crystals from LIMHP-CNRS displayed cross-hatched bands of low-order interference colors when viewed through the {100} face (figure 5A). Small areas of localized strain with relatively higher order interference colors surrounding tiny defect centers also were observed. Much higher order interference colors were seen at the four corners in sample no. 66875 (figure 5B), and outside the substrate window in sample 66876 (figure 5C), indicating strong residual internal strain and accumulated dislocations in these regions.

Figure 2. When viewed perpendicular to the growth direction and parallel to the {100} face, CVD synthetic diamond sample no. 67404 displays a dark brown color zone (see arrows) parallel to {100}. The yellow “triangle” to the lower right of the arrows is the substrate of HPHT synthetic diamond. Photomicrograph (taken before substrate was removed) by W. Wang; total thickness of the specimen was 3.36 mm.



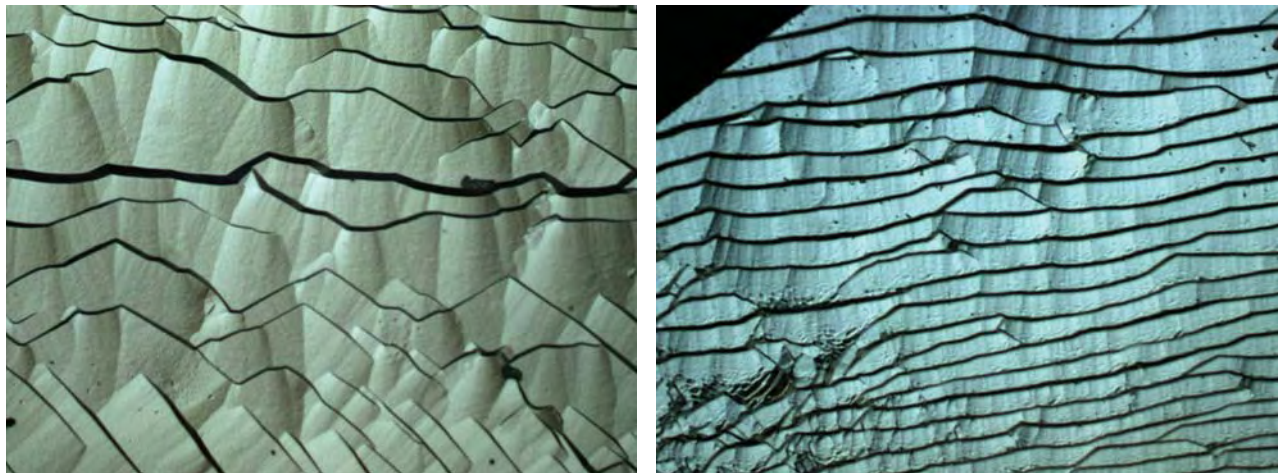


Figure 3. Differential interference contrast microscopy revealed sequences of growth steps with terrace regions separated by inclined risers on the (100) surface of the nitrogen-doped CVD synthetic diamonds (left, no. 67404; right, no. 66875). Photomicrographs by Alexandre Tallaire; magnified 50 $\times$ .

An outstanding feature evident from the anomalous birefringence is that bundles of dislocations nucleated along the boundary between the substrate and its CVD synthetic diamond overgrowth and are uniformly parallel to the growth direction, as first pointed out by Martineau et al. (2004). As a result, the “shadow” of the substrate can be clearly seen in the birefringence image, even after its removal. This feature was observed in all crystals except for no. 66669.

Figure 4. With a gemological microscope, portions of this high-purity CVD synthetic diamond (no. 66675) display surface growth features similar to those observed on the nitrogen-doped crystals. The apparent color is caused by the yellow substrate of HPHT synthetic diamond, which was not removed. Photomicrograph by W. Wang; image width is approximately 2.9 mm.



In addition, the region outside the substrate “shadow” typically showed higher-order interference colors (figure 5C). Anomalous birefringence caused by residual internal strain is also a common feature of natural type IIa diamond. While large variations in intensity have been observed, natural type IIa diamonds generally show stronger anomalous birefringence than is seen in CVD synthetic diamonds (see, e.g., Moses et al., 1999). Banded and “tatami” patterns are the predominant strain characteristics of natural type IIa diamonds (figure 6, A and B; see, e.g., Smith et al., 2000); as shown in figure 5, the characteristic strain pattern of single-crystal CVD synthetic diamond is distinctly different. HPHT-grown synthetic type IIa diamonds most commonly show no strain (figure 6C).

All five of the samples tested were inert to the UV radiation emitted by a standard gemological UV lamp, and no phosphorescence was observed. In contrast, some of the Apollo nitrogen-doped samples studied by Wang et al. (2003) fluoresced a very weak orange, orange-yellow, or yellow to long-wave UV, and a very weak to moderate orange to orange-yellow to short-wave UV. Orange fluorescence of varying intensity to both long- and short-wave UV radiation was also observed in many of the Element Six nitrogen-doped crystals; in contrast, those of high purity were inert (Martineau et al., 2004). Most natural type IIa diamonds are inert to both long- and short-wave UV. Only a few natural type IIa diamonds are known to fluoresce blue or orange to standard UV radiation. In contrast, most HPHT synthetic type IIa diamonds show weak to moderately strong yellow-green fluorescence and moderate to strong yellow-green phosphorescence to short-wave UV radiation (see, e.g., Shigley et al., 1997).



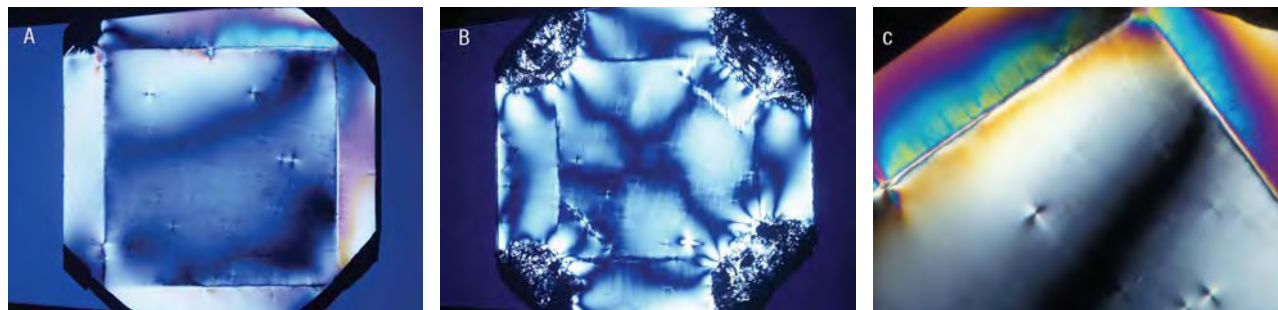


Figure 5. The high-purity crystal in image A (no. 66876), which measures 4.4 mm across, displays the characteristic strain pattern of a CVD-grown diamond when viewed perpendicular to a cubic crystal face (100). The “shadow” of the substrate is clearly visible even after its removal, as the large square with relatively lower order interference colors in the center of the sample. Much higher order interference colors were observed at the four corners of nitrogen-doped sample no. 66875 (B, 6.3 mm across) and in the area outside the substrate “shadow” of sample no. 66876 (C, image width is 2.9 mm), indicating strong residual internal strain and accumulated dislocations in these regions. Photos A and B by W. Wang, and photomicrograph C by Shane McClure; crossed polarizers.

**Spectroscopic Features. Photoluminescence.** PL spectra showed that three of the samples were nitrogen doped and three others were of high purity, as expected from the growth methods employed (see figure 7 and table 1). Several laser excitations were used to obtain maximum sensitivity over various energy regions. Using high-energy 488.0 nm laser excitation allows the detection of trace amounts of 3H, H3, and H4 defects. The 514.5 nm laser system is more sensitive at detecting the 637 nm [(N-V)<sup>-</sup>] defect, and 632.8 nm excitation is ideal for detecting traces of Si impurity.

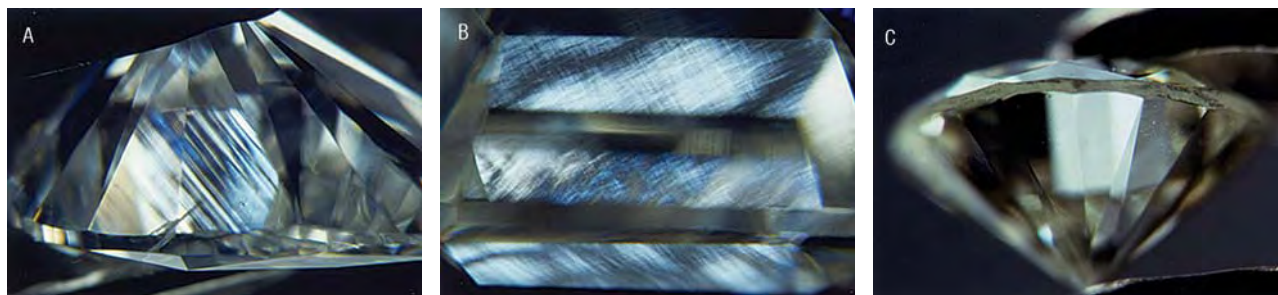
Major PL features in the nitrogen-doped samples include strong emissions of (N-V)<sup>0</sup> with its zero-phonon line (ZPL) at 575 nm and (N-V)<sup>-</sup> with its ZPL at 637 nm, weak emission pairs at 596–597 nm, and Si-related emission at 737 nm (e.g., Bergman et al., 1993).

In two specimens (nos. 66669 and 66875), the intensity of the 637 nm emission was stronger than or close to that of the 575 nm. However, the other nitrogen-doped sample (no. 67404) showed

the opposite trend. During crystal growth, samples 66669 and 66875 were doped with moderate and low nitrogen contents, respectively. In contrast, sample 67404 was doped with only a very small amount of nitrogen. It seems that the higher the nitrogen content is, the higher the intensity of the 637 nm emission compared to that of the 575 nm will be. When 488 nm laser excitation was employed, the integrated intensity ratio (i.e., the area of a peak, rather than its height) of 637/575 was 1.31 for sample 66669, 0.96 for sample 66875, and only 0.07 for sample 67404. These observations indicate a possible correlation between the content of doped nitrogen and the concentrations of (N-V)<sup>0</sup> and (N-V)<sup>-</sup> centers generated. They are consistent with the suggestion that (N-V)<sup>0</sup> is initially incorporated during CVD growth, and (N-V)<sup>-</sup> appears and intensifies as the nitrogen content further increases (M. Newton, pers comm., 2005).

In contrast to the nitrogen-doped CVD synthetic diamonds, the two high-purity samples (nos. 66876 and 67405) displayed virtually no PL features. Only

Figure 6. In contrast to CVD synthetic diamonds, natural type IIa diamonds typically show banded and “tatami” patterns with low first-order interference colors (A, B). HPHT-grown synthetic type IIa diamonds most commonly show no strain (C). Photomicrographs by Christopher Smith; crossed polarizers.





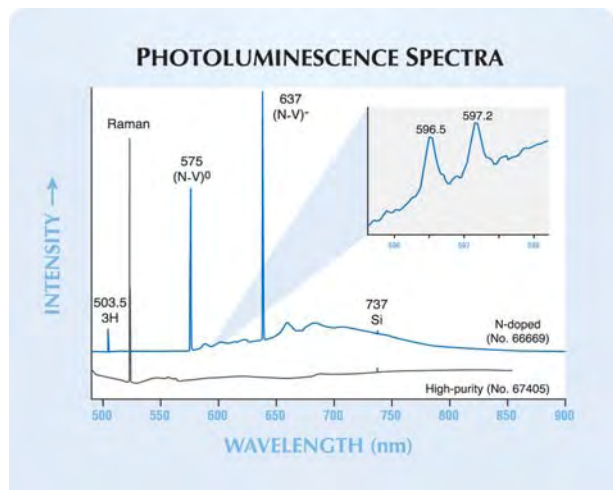
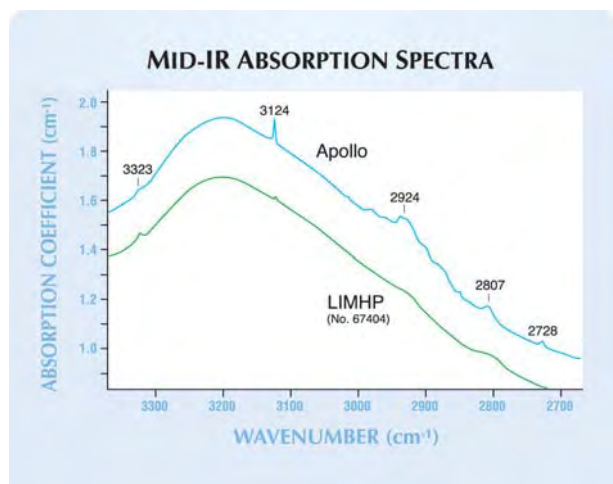


Figure 7. Low-temperature photoluminescence spectra collected using an Ar-ion laser (488 nm excitation) revealed clear differences between the nitrogen-doped and high-purity CVD synthetic diamonds. Strong emissions at 575 and 637 nm—and weak emissions at 503.5, 596, 597, and 737 nm—were detected in the three nitrogen-doped samples. Three high-purity CVD synthetic diamonds displayed only a very weak emission at 737 nm caused by trace Si impurity, although this emission was extremely strong in one N-doped sample (no. 67404).

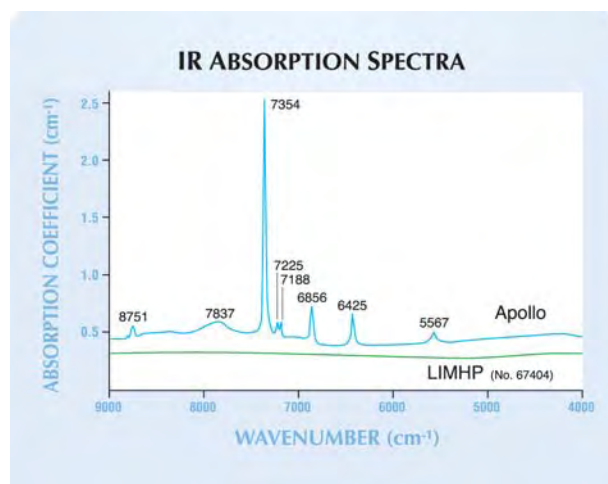
Figure 8. Except for brown sample no. 67404, the CVD synthetic diamonds from LIMHP-CNRS did not show any defect-related absorption in the mid-infrared range. Sharp, very weak absorptions at 3323 and 3124  $\text{cm}^{-1}$ , and two relatively broad absorptions at 2924 and 2807  $\text{cm}^{-1}$ , were detected in sample no. 67404. In contrast, these H-related absorptions were observed in many of the Apollo CVD synthetic diamonds examined by Wang et al. (2003). The spectra are shifted vertically for clarity.



a very weak 737 nm emission was detected. Nevertheless, it appears that the high-purity crystals from LIMHP-CNRS are slightly less pure than those from Element Six examined by Martineau et al. (2004), in which no Si-related emission was detected. Sample no. 67405 also showed a very weak emission line at 953 nm when 780 nm laser excitation was employed. High-purity crystal no. 66675 displayed very weak emissions at 575 nm and 637 nm, which are very likely from its type Ib HPHT synthetic diamond substrate. This explanation is supported by the occurrence of a very weak H3 emission (zero phonon line at 503.2 nm), which certainly is from the substrate.

In addition, very weak emissions at 563, 699, 766, and 841 nm were occasionally observed in the LIMHP-CNRS samples (again, see table 1). The 3H defect, with a zero-phonon-line position at 503.5 nm (slightly higher than that of H3 at 503.2 nm), is typically radiation related (Collins et al., 1989). The 3H defect is relatively unstable, and should be annealed out at typical CVD growth temperatures (Zaitsev, 2001); nevertheless, the 3H defect was detected in all three nitrogen-doped crystals and in one high-purity crystal (no. 66675). In contrast, the 3H defect was not detected in any of the Apollo

Figure 9. The CVD synthetic diamonds from LIMHP-CNRS did not show any defect-related absorption in the near-infrared range. In contrast, most Apollo CVD synthetic diamonds examined by Wang et al. (2003) displayed relatively strong absorptions in this range. Of the five specimens examined, only the light brown crystal (no. 67404) exhibited a very weak absorption at 6856  $\text{cm}^{-1}$  (not visible below). The spectra are shifted vertically for clarity.



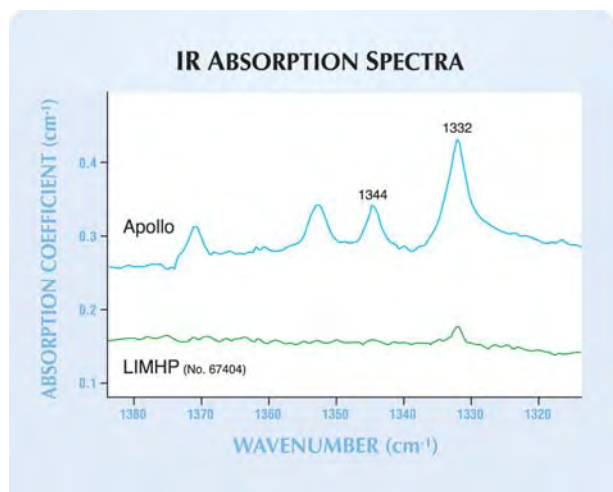


Figure 10. None of the CVD synthetic diamonds from LIMHP-CNRS examined showed the absorption at  $1344\text{ cm}^{-1}$  associated with trace amounts of isolated nitrogen, which was present in several of the Apollo CVD synthetic diamonds studied by Wang et al. (2003). The spectra are shifted vertically for clarity.

products (Wang et al., 2003) or reported by Martineau et al. (2004) for CVD synthetic diamond samples produced by Element Six.

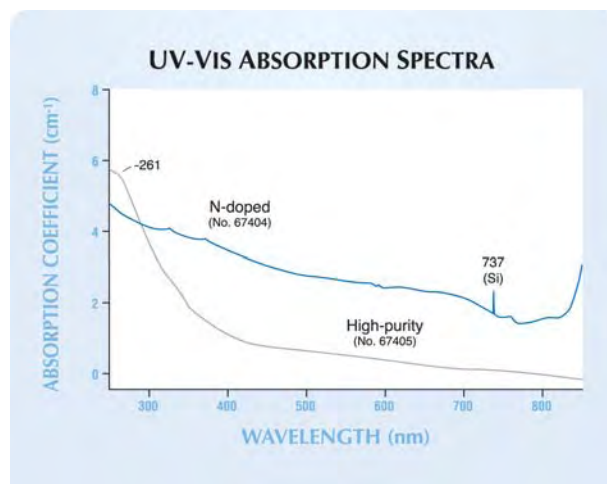
This apparent discrepancy might be explained by the fact that two of the nitrogen-doped crystals (nos. 66875 and 66669) and one high-purity crystal (no. 66876) had previously been analyzed by cathodoluminescence, which can introduce weak radiation damage (Steed et al., 1999). However, no 3H features were detected in high-purity crystal no. 66876, while nitrogen-doped crystal no. 67404 was not analyzed with any method involving cathodoluminescence or X-radiation but also showed a weak 3H. Still, the presence of the 3H defect in four crystals examined in this study is not likely to be an as-grown feature but rather may have been introduced accidentally afterwards, perhaps by exposure to X-rays in an airport security checkpoint.

**IR Spectroscopy.** Infrared absorption spectroscopy revealed that all samples were type IIa. Except for the light brown crystal (no. 67404), no defect-related absorptions were detected in the infrared region (figures 8 and 9). In contrast, the Apollo products examined by Wang et al. (2003) and the nitrogen-doped Element Six CVD synthetic diamond samples studied by Martineau et al. (2004) usually showed strong hydrogen-related absorptions in both the mid- and

near-infrared regions. In the LIMHP-CNRS samples, weak, sharp absorptions at  $3323$  and  $3124\text{ cm}^{-1}$ , and two broad absorptions at  $2924$  and  $2807\text{ cm}^{-1}$ , were observed only in the light brown crystal. In addition, none of the crystals examined showed any absorption due to trace amounts of isolated nitrogen at  $1344\text{ cm}^{-1}$  (figure 10), which was present in many of the Apollo CVD synthetic diamonds examined by Wang et al. (2003). Hydrogen-related absorptions in the infrared region were important identification features for the Apollo CVD synthetic diamonds, since many of these features are specific to CVD synthesis (Martineau et al., 2004). However, they were not diagnostic for the CVD synthetic diamonds in this study.

**UV-Vis-NIR Spectroscopy.** Low-temperature absorption spectra collected in the UV-Vis-NIR range revealed few notable features (figure 11). Spectra from the high-purity and the near-colorless nitrogen-doped samples were very flat in the visible range, and increased gradually into the UV region. A weak and broad band at  $\sim 261\text{ nm}$  was detected in sample no. 67405; its assignment is not certain, but

Figure 11. The low-temperature absorption spectrum of this high-purity CVD synthetic diamond (no. 67405) is rather flat in the visible-light range, and increases gradually in the UV region. The assignment of a weak and broad band at  $\sim 261\text{ nm}$  is not clear, but this absorption is likely not due to isolated nitrogen. In the brown nitrogen-doped CVD-grown diamond (no. 67404), the absorption increases gradually toward lower wavelengths. A distinct absorption at  $737\text{ nm}$  due to a Si impurity also was observed. The spectra are shifted vertically for clarity.



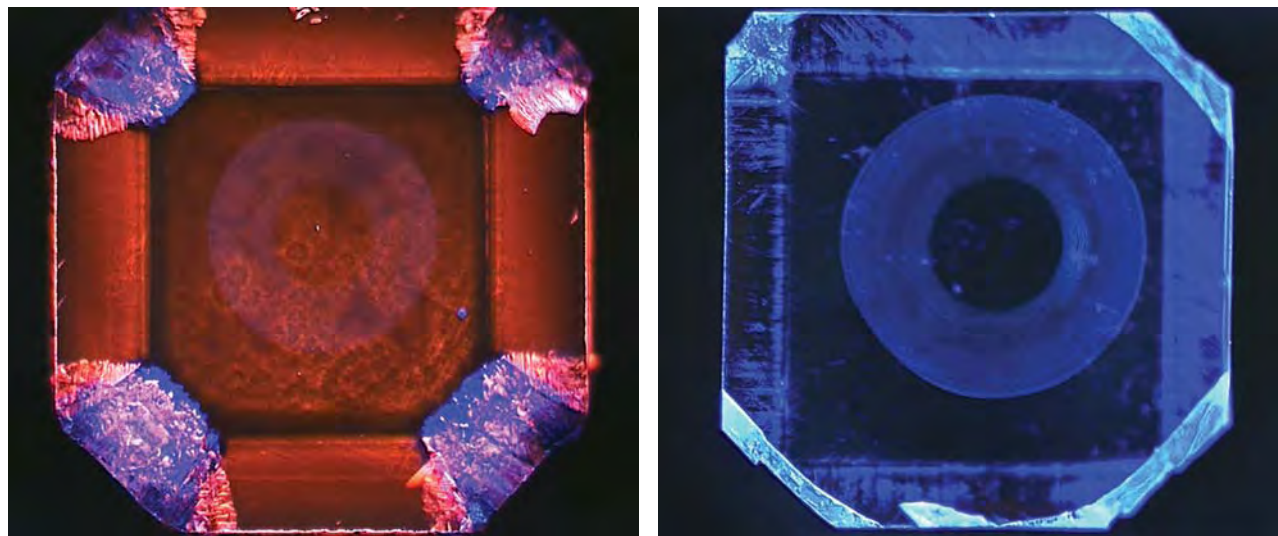


Figure 12. In the DTC DiamondView, the nitrogen-doped CVD-grown crystals showed a strong and characteristic orange to orangy red luminescence (sample no. 66875, left). In contrast, the high-purity crystals showed only a very weak blue fluorescence (sample no. 66876, right). The original positions of the substrates are visible as the darker square-shaped patterns in the center of the images. The circular areas within the squares are from the sample holder. Photos by W. Wang.

the band is most likely not due to isolated nitrogen (Zaitsev, 2001). In the light brown nitrogen-doped CVD-grown diamond (no. 67404), the absorption increased gradually toward lower wavelengths. A distinct absorption at 737 nm ( $0.64 \text{ cm}^{-1}$  absorption coefficient) was also observed in this sample. The intensity of this peak was stronger than that of all the Apollo products we have examined so far. Early products from Element Six showed an emission line at 737 nm in the photoluminescence spectrum, but its absorption intensity was not reported. In addition, this feature was not detected in samples grown more recently by Element Six (Martineau et al., 2004).

**DiamondView Imaging.** When examined with the DiamondView, the nitrogen-doped samples exhibited strong orange to orangy red luminescence due

to both  $(\text{N-V})^0$  and  $(\text{N-V})^-$  centers (figure 12, left). In contrast, the high-purity synthetic crystals luminesced very weak blue (figure 12, right). The blue luminescence is believed to emanate from bundles of dislocations in arrangements not seen in natural diamond (Martineau et al., 2004). In figure 12 (left), blue luminescence also can be seen at the four corners of nitrogen-doped crystal no. 66875, where extensive dislocations appeared in the anomalous birefringence image (figure 5B).

Two crystals showed blue phosphorescence in the DiamondView. One (no. 67404) was nitrogen doped (figure 13, left), and the other (no. 67405) was of high purity (figure 13, right). Blue phosphorescence is common in many natural type IIb diamonds and may also occur in some HPHT-grown synthetic type IIa diamonds (Shigley et al., 1997; King et al., 1998), but it is rarely seen in

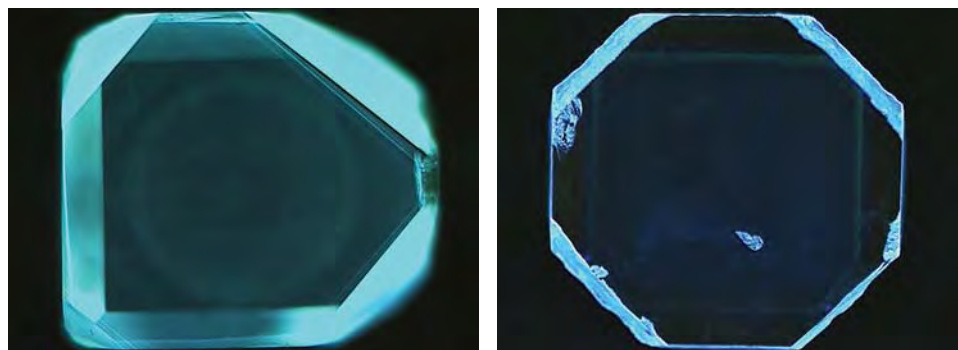


Figure 13. In the DiamondView, two of the studied CVD samples (left, no. 67404; right, no. 67405) showed moderately strong blue phosphorescence, which is rarely observed in natural type IIa diamonds. Photos by W. Wang.



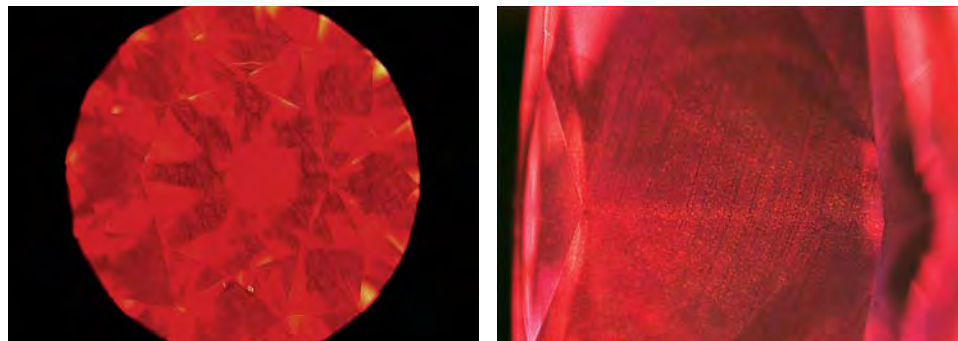


Figure 14. Characteristic “mosaic” networks of polygonized dislocations (left, 6.44 mm in diameter) and dislocations lying in slip bands (right, 3.9 mm depth) are the major features of natural type IIa diamonds with orange fluorescence seen in the DiamondView. Photos by W. Wang (left) and Paul Johnson (right).

natural type IIa diamonds. As in the aforementioned birefringence images, the original position of the HPHT-grown synthetic substrate also was observable in most DiamondView fluorescence and phosphorescence images.

Natural type IIa diamonds usually show blue fluorescence in the DiamondView, and they typically display characteristic “mosaic” networks of polygonized dislocations or dislocations lying in slip bands (Martineau et al., 2004). A few natural type IIa diamonds exhibit orange luminescence, similar to that of nitrogen-doped CVD synthetic diamonds. Our extensive examinations have revealed that “mosaic” networks and slip bands are also the predominant features of natural type IIa diamonds that show this orange fluorescence (figure 14).

## IDENTIFICATION FEATURES

The CVD synthetic diamonds from LIMHP-CNRS were produced solely for research purposes, but in the event a similar product ultimately reaches the gem market it is important to understand the differences between these samples and natural diamonds, as well as other gem-quality CVD synthetics currently being produced. Although the products examined in this study showed considerable variation in color and purity, it is clear that deposition of non-diamond carbon during crystal growth at relatively high growth rates can be minimized, leading to the formation of near-colorless gem-quality crystals. The relatively narrow thickness of CVD overgrowth (no more than 1.64 mm in the crystals examined) would limit their potential jewelry application to very small gems. However, other manufacturers (Apollo Diamond, Element Six, and the Carnegie Institute) have demonstrated their ability to grow high-quality CVD crystals thick enough to be faceted as gems. It is feasible

that LIMHP-CNRS has a similar capability.

The new LIMHP-CNRS synthetic diamonds showed distinct differences in optical and spectroscopic properties from the suite of Apollo products examined by Wang et al. (2003), as well as from the Element Six CVD samples examined by Martineau et al. (2004). Fortunately, the LIMHP-CNRS samples we examined could be identified on the basis of their characteristic birefringence images, orange or blue luminescence features in the DiamondView, and/or PL spectroscopic features (i.e., emission at 737 nm and a 596/597 nm pair). Very few natural type IIa diamonds fluoresce orange or orangy red in the DiamondView, so this reaction is a good indication that further testing is necessary. One CVD-specific PL spectroscopic feature is the weak doublet at 596 and 597 nm, which was detected in all three nitrogen-doped samples and in one high-purity CVD crystal in this study. More importantly, the Si-related defect at 737 nm, which has never been reported in natural diamonds, occurred at varying intensity in all the samples (both nitrogen doped and high purity) examined in this study, making it a very useful identification feature.

## CONCLUDING REMARKS

CVD synthetic diamonds from LIMHP-CNRS have been created solely for research purposes, as both nitrogen-doped and high-purity samples. These type IIa products showed considerable variation in color and impurity concentration. This study revealed some subtle but clear differences between the LIMHP-CNRS products and the suite of Apollo products examined by Wang et al. (2003) and the Element Six products examined by Martineau et al. (2004). While the LIMHP-CNRS synthetics show almost no absorption features in the infrared

region, they can be reliably identified based on their characteristic birefringence images, luminescence features in the DiamondView, and/or PL spectroscopic features.

With the rapid progress in CVD growth tech-

niques, larger and better-quality synthetic diamonds are likely to be produced. Identification features will probably change to some extent with the continued development of CVD synthesis techniques.

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# INCLUSIONS IN TRANSPARENT GEM RHODONITE FROM BROKEN HILL, NEW SOUTH WALES, AUSTRALIA

Paul W. Millstedt, Terrence P. Mernagh, Vincent Otieno-Alego, and Dudley C. Creagh

Solid, vapor, and fluid inclusions in transparent gem rhodonite crystals from Broken Hill, New South Wales, Australia, have been identified for the first time using Raman spectroscopy and gemological/ petrographic techniques. Among the solid inclusions are sphalerite, galena, quartz, and fluorite. The rhodonite also contained hollow needle-like tubes and negative rhodonite crystals. Three-phase inclusions were found to contain a saline liquid, a gaseous mixture of nitrogen (N<sub>2</sub>) and methane (CH<sub>4</sub>), and ilmenite crystals.

Gem rhodonite crystals have been recorded from Broken Hill, New South Wales, Australia, for at least 100 years. Most of these crystals have been recovered from the North mine and Zinc Corp./NBHC mines; however, they are widely distributed throughout the deposit. A number of beautiful transparent crystals, less than 1 cm thick, have been recorded (Birch, 1999; see, e.g., figure 1), with some rare specimens as large as several centimeters across. The authors know of at least six crystals that have been successfully faceted, producing stones that range from 0.15 to 10.91 ct, and these display a rich pink to brownish red color similar to that seen in pink-to-red spinel. The 10.91 ct stone (figure 2), the largest faceted rhodonite ever recorded from Broken Hill, is currently on display at Toronto's Royal Ontario Museum. No rhodonite cabochons from this locality have been documented. Because so little is known about this gem material, this article characterizes a variety of inclusions found in gem rhodonite from the North mine at Broken Hill.

## BACKGROUND

Gem-quality rhodonite ([Mn,Fe,Ca]SiO<sub>3</sub>) is known from the primary silver-lead-zinc sulfide orebodies centered at Broken Hill, arguably the most famous mining town in Australia (figure 3) and one of the richest sources of gem rhodonite crystals in the world.

**Location.** Broken Hill lies on the inland edge of the Western Plains of New South Wales at the foot of the Barrier Ranges, on the edge of the Sundown Hills, 1,100 km from Sydney and 43 km from the border with South Australia (Solomon, 1988). The Broken Hill deposit, renowned as one of the most outstanding mineral deposits in the world, is hosted in what geologists have defined as the Broken Hill block. Some 2,000 separate mineral deposits are distributed throughout the block, over an area of 4,000 km<sup>2</sup> (Barnes, 1986).

**Regional Geology and Occurrence of Rhodonite.** Up to nine separate, but closely related, lenses and lodes are hosted in rocks of the Willyama Supergroup at Broken Hill (Stevens et al., 1983). Differences in the orebodies are reflected in the relative proportions of lead and zinc, as represented by the minerals galena and sphalerite, respectively (Johnson and Klinger, 1975; Plimer, 1979, 1984). In addition to these two minerals, rhodonite from Broken Hill may be associated with spessartine, calcite, hedenbergite, bustamite, fluorapatite, fluorite, quartz, and pyroxmangite (Birch, 1999).

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See end of article for About the Authors and Acknowledgments.  
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Figure 1. The Broken Hill mines in New South Wales, Australia, have produced attractive gem-quality rhodonite crystals, such as this 2.9-cm-long prism. Photo by Wendell Wilson, courtesy of The Mineralogical Record.

Most of the orebodies at Broken Hill have a granular texture in both non-ore (gangue) and sulfide portions. Specimens of ore collected from 3 Lens, one of the two known lead lodes at North mine, typically display this texture (figure 4). Local geologists refer to the lead lodes as having layering in the ore, known to enclose pods and “boudins” (sausage-shaped segments) of low-grade rhodonite, bustamite or manganhedenbergite, other gangue minerals, and sulfides. Overall, masses of rhodonite and bustamite have exceeded 20 m across (Maiden, 1975).

**History of Mining at Broken Hill.** The Broken Hill orebody was pegged in September 1883 and later subdivided into seven mining leases called blocks (which are distinct from the Broken Hill block discussed above). Block 17, then known as the “Cosmopolitan,” was established in December 1883 and acquired by the North Broken Hill Silver Mining Co. in 1885 (figure 5). Although some secondary silver and lead ore was mined in 1888, this was rapidly exhausted, and in 1897 the North Broken Hill Silver Mining Co. began mining the primary sulfide ore.

North Broken Hill Ltd. acquired Block 17 in 1912 and established itself as a major employer in the city of Broken Hill (Koenig, 1983). During peak production, between 1970 and 1975, some 800–900 workers were employed by North Broken Hill Ltd. at this operation.

The North mine leases comprise mainly those parts of the deposit that geologists have referred to as the lead lodes 3 Lens and 2 Lens. In the 1970s, miners working the stopes of the 25, 26, and 27 levels of No. 3 shaft, some 350 m from the surface, made a concerted effort to ensure the preservation of a significant quantity of rhodonite crystals by skillfully separating them from the sulfide orebody. These intense pinkish to brownish red translucent-to-opaque tabular crystals, reaching up to 10 cm

Figure 2. This 10.91 ct modified emerald step cut is believed to be the largest faceted rhodonite from the Broken Hill mines. The stone was cut by Maria Atkinson and is currently on display at the Royal Ontario Museum, Toronto. Photo by David Atkinson.





Figure 3. The city of Broken Hill is located in western New South Wales, Australia. The North mine is located in the northern part of the mining field.

across, were occasionally associated with random clusters and pockets of beautiful transparent crystals about 1 cm wide. These specimens soon became highly prized by the wider mineralogical community in Broken Hill and beyond.

Many Australian museums and private collec-

tors have preserved some outstanding specimens of this transparent rhodonite from the Broken Hill orebody, both in matrix (e.g., figure 6) and as individual crystals (again, see figure 1). North Broken Hill Ltd. closed its operations in 1993, but development plans for a smaller mining operation by the current lease-holder, Perilya Pty Ltd., are now under way.

**Reported Properties of Broken Hill Rhodonite.** The typical composition of rhodonite from Broken Hill is 50–70 mol.%  $\text{MnSiO}_3$ , 18–20 mol.%  $\text{CaSiO}_3$ , and 10–20 mol.%  $\text{FeSiO}_3$ ; traces of Zn and Mg may also be present (Albrecht and Peters, 1980). Absorption bands at 523–536 nm ( $19100\text{--}18650\text{ cm}^{-1}$ ), caused by  $\text{Fe}^{2+}$  and  $\text{Mn}^{2+}$ , are typical for transparent gem rhodonite from the North mine (Bank et al., 1974). Refractive indices for similar specimens were recorded by Diehl and Berdesinski (1970) as  $n_\alpha = 1.725$ ,  $n_\beta = 1.729$ , and  $n_\gamma = 1.737$ . Generally speaking, rhodonite has a density in the range 3.55–3.76  $\text{g/cm}^3$  (Gaines et al., 1997). Bank et al. (1974) reported a value of 3.74  $\text{g/cm}^3$  for one transparent specimen from Broken Hill.

A recent investigation into the faceting of transparent rhodonite from Broken Hill revealed a notable suite of solid and fluid inclusions, which we subsequently studied by Raman spectroscopy and petrographic techniques, as reported here.

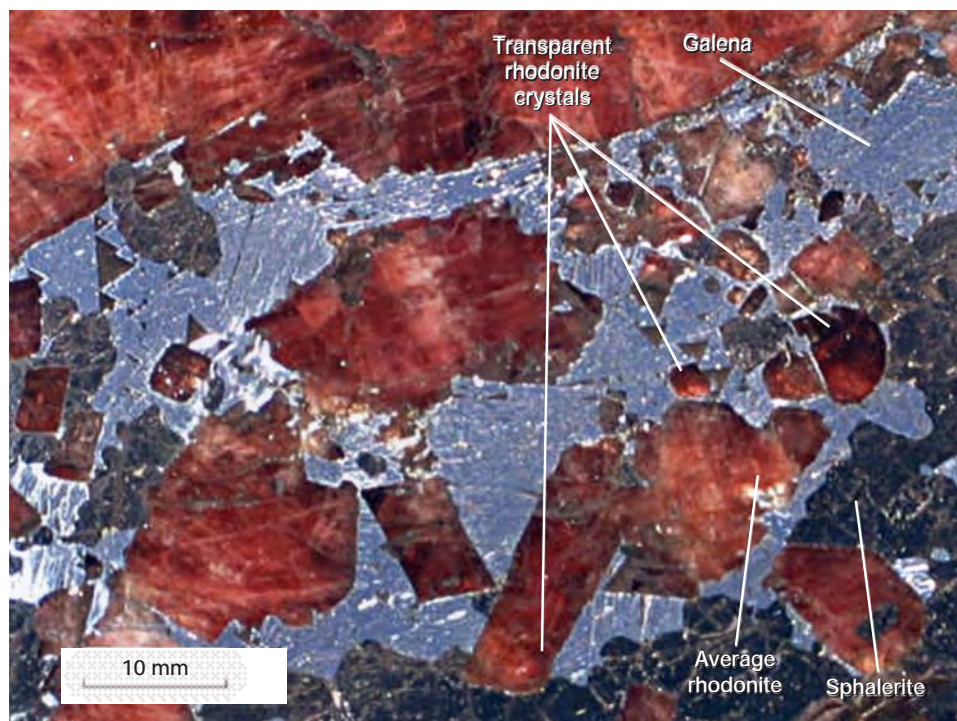


Figure 4. This polished ore sample from the 25/26 level of the North mine (specimen 1) contains crystals of galena (3–8 mm), sphalerite (3–10 mm), and subhedral to euhedral rhodonite (2–70 mm). Note the several transparent rhodonite crystals. Photomicrograph by Paul Millsted.



*Figure 5. The North Broken Hill Silver Mining Co. acquired Block 17 at Broken Hill, which would later become known as the North mine, in 1885. This photo of the mining operation was taken in 1888 (from Koenig, 1983).*



## MATERIALS AND METHODS

Eight transparent rhodonite crystals (5–25 mm long), recovered from 3 Lens, 25/26 level, of the North mine were prepared and examined. Six of the crystals (specimens 4–9) were sliced, resulting in 12 sections that were polished on both sides for optimal

*Figure 6. This specimen of rhodonite crystals embedded in calcite ( $3 \times 2.5 \times 2$  cm, from level 17 of the Zinc Corp. mine) is part of the Albert Chapman Collection at the Australian Museum, Sydney. Photo by Carl Bento, Australian Museum (No. D49967).*



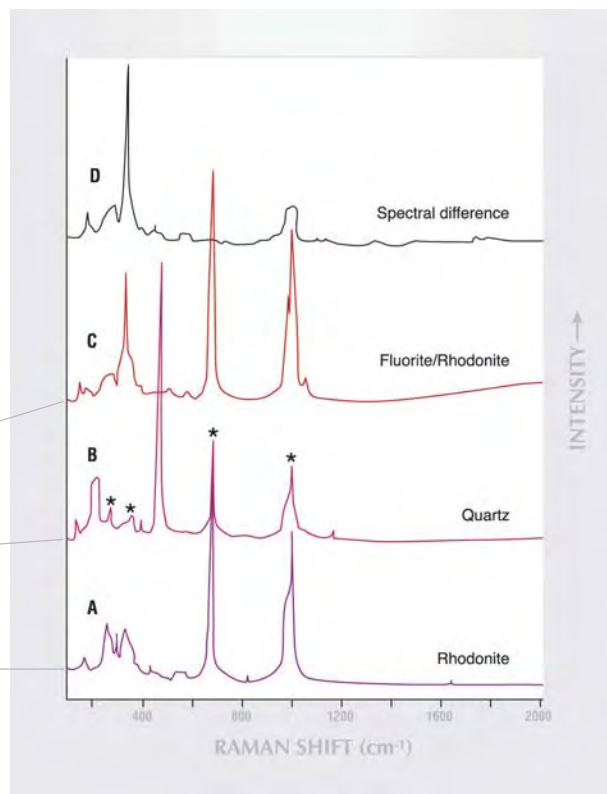
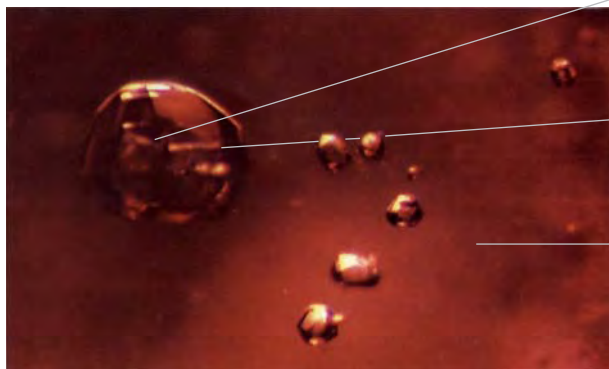
inclusion identification. The thickness of the sections ranged from 100  $\mu\text{m}$  to 2 mm, and most contained subsurface solid or fluid inclusions ranging from  $<1$   $\mu\text{m}$  to 100  $\mu\text{m}$  in diameter. One crystal, specimen 3, was retained intact for the duration of the experimental work. We determined gemological properties (including visible absorption spectra) using standard gemological instruments on specimen 2, a faceted stone (figure 7). (Specimen 1 was the ore sample shown in figure 4.)

*Figure 7. Gemological properties were taken on this 0.86 ct faceted rhodonite ( $5.4 \times 5.4 \times 3.9$  mm; specimen 2) from the North mine at Broken Hill, which was cut by Ralph Westen. Photo by Paul Millstead.*





Figure 8. Solid inclusions in rhodonite specimen 3 (left) were identified by Raman spectroscopy (right) as quartz and fluorite. (The asterisks noted on the quartz spectrum indicate the rhodonite peaks at 996/975, 670, 324, and 207  $\text{cm}^{-1}$ .) The spectral difference (D)—the removal of spectrum A for the host rhodonite from spectrum C—positively identified the minor solid inclusion as fluorite by reference to the Raman database. The diameter of the largest inclusion is about 200  $\mu\text{m}$ . Photomicrograph by Paul Millsted.



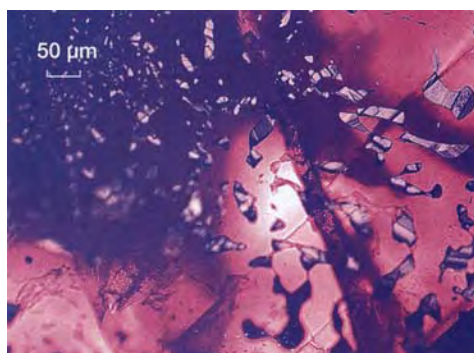
Microscopic observations of specimens 3–9 were initially performed using a Leica DMR polarizing microscope. The types of inclusions, their sizes and shapes, and the number of phases they contained were noted for these specimens, as well as for a 15 × 20 × 35 mm rhodonite crystal in a matrix of galena (specimen 10, the eighth transparent crystal).

Raman spectra were recorded for solid inclusions in specimen 3 using a Renishaw Raman microspectrometer with a 632.8 nm He-Ne laser as the excitation source. The instrument was used in confocal mode for maximum spatial resolution. With this setting, individual solid inclusions ini-

tially pinpointed using transmitted light were targeted by focusing the laser beam via the 50× microscope objective.

Raman spectra for the vapor phase of three-phase inclusions were also recorded *in situ* for one of the sections cut from specimen 4 using a Dilor SuperLabram microspectrometer. These inclusions were analyzed with a higher-energy 514.5 nm laser excitation. A 100× microscope objective was used to increase the laser intensity at the focal point within the inclusions. The spectra of the vapor phase were recorded from 3800 to 1000  $\text{cm}^{-1}$  using a single 20-second integration time per spectrum. The detection limits for specific gases are dependent on the

Figure 9. Many of the samples contained galena inclusions, as seen here along fractures in specimen 6. A closer view (right) shows contact-twin lamellae evident as diagonal striations along cleavages, together with a surficial fluid. Photomicrographs by Paul Millsted; transmitted light.



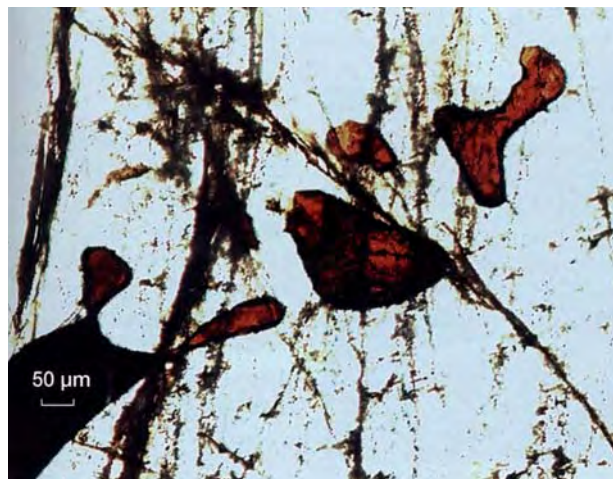


Figure 10. Many samples also contained sub-angular elongate sphalerite inclusions, such as those shown here in specimen 7. Photomicrograph by Paul Millsted.

instrumental sensitivity, the partial pressure of each gas, and the optical quality of each fluid inclusion. Raman detection limits (Wopenka and Pasteris, 1987) are estimated to be around 0.1 mol.% for CO<sub>2</sub>, O<sub>2</sub>, and N<sub>2</sub>, and about 0.03 mol.% for H<sub>2</sub>S and CH<sub>4</sub>. Errors in the calculated gas ratios are generally less than 1 mol.%.

## RESULTS

**Gemological Properties.** The refractive indices determined from specimen 2 were  $n_{\alpha} = 1.732$  and  $n_{\gamma} = 1.745$ . Pleochroism was generally weak, showing colors of yellowish red, pinkish red, and pale yellowish red. The optic axis angle (2V) yielded a biaxial positive optic sign. The dominant morphological forms were (001), (110), and (110). Specific gravity determinations yielded a value of 3.65.

The visible absorption spectra revealed lines at 408 and 412 nm and a diffuse weak band at 455 nm. A strong narrow absorption line at 503 nm and a broad band at 548 nm were also recorded. The sample fluoresced a dull dark red to both long- and short-wave UV radiation.

### Raman and Petrographic Analyses of Inclusions.

Figure 8 illustrates a large solid inclusion (about 200 μm in diameter) that contained two solid phases. After subtraction of the rhodonite peaks at 996 and 975 cm<sup>-1</sup>, one of these phases was identified as quartz and the other as fluorite. A suite of solid inclusions identified using petrological techniques included elongate or rounded twinned gale-

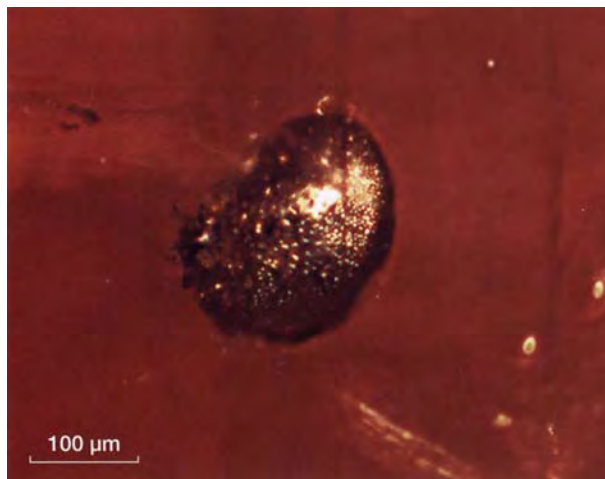


Figure 11. A number of rounded pyrrhotite grains were seen in specimen 10, but not in any of the other samples examined. Pyrrhotite has been found throughout the Broken Hill ore deposit. Photomicrograph by Paul Millsted; reflected light.

na (figure 9), with contact-twin lamellae evident as diagonal striations along cleavages together with residual fluid, as well as sub-angular elongate sphalerite (figure 10) and rounded pyrrhotite crystals (figure 11).

Also seen were several generations of negative crystals that were commonly aligned in preferred crystallographic orientations (figure 12); euhedral negative rhodonite crystals that formed in areas containing sphalerite (figure 13); and thin tubes that appeared to be hollow, from which no Raman signals could be recorded.

A number of specimens had three-phase inclusions, such as the suite shown in figure 14. These inclusions typically contained CH<sub>4</sub> and N<sub>2</sub> in the vapor phase (figure 15), a liquid of moderate to high salinity (based on the maximum around 3450 cm<sup>-1</sup> and the low intensity of the peak at 3300 cm<sup>-1</sup>), and a solid identified as ilmenite (figure 16).

Figure 14A shows a suite of euhedral negative crystals. A particularly large negative crystal in this suite contained a vapor bubble (~15 vol.%) and an opaque solid (~5 vol.%). Raman analysis of that vapor phase revealed 49 mol.% CH<sub>4</sub> and 51 mol.% N<sub>2</sub>; the vapor phase of a similar inclusion in figure 14B contained 53 mol.% CH<sub>4</sub> and 47 mol.% N<sub>2</sub>. The needle-like inclusions with negative crystal shapes (which were commonly aligned along preferred crystallographic orientations) had the same chemical composition but different phase ratios. For example, the needle-like inclusion in figure 14D contained 30 vol.% vapor (CH<sub>4</sub> ± N<sub>2</sub>), 50 vol.% saline liquid, and 20 vol.% ilmenite. We

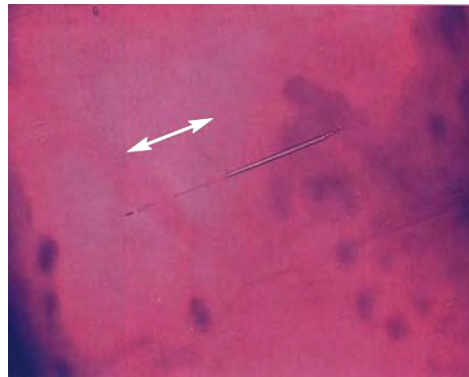
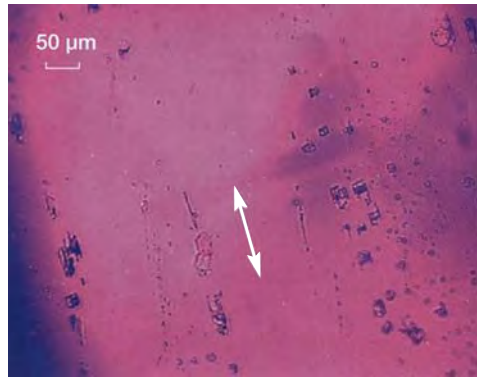


Figure 12. Also seen (here, in specimen 5) were several generations of hollow negative crystals aligned along a preferred crystallographic orientation, as shown by the white arrows. Photomicrographs by Paul Millstead.

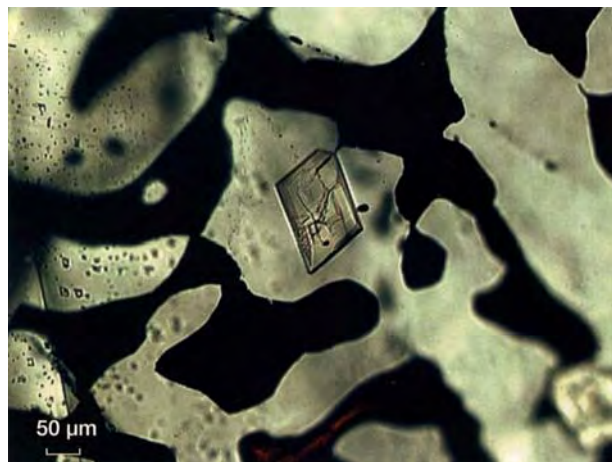
believe this is due to leakage of fluid from the inclusions along the healed fractures, such as those that are evident at each end of the inclusion in figure 14D.

Several additional photomicrographs and Raman spectra of the inclusions identified in this study are available in the *Gems & Gemology* Data Depository at [www.gia.edu/gemsandgemology](http://www.gia.edu/gemsandgemology).

## DISCUSSION

The gemological properties obtained in this study were consistent with those for rhodonite in the literature, although the R.I. values were higher than those given by Diehl and Berdesinski (1970) and Bank et al. (1973a). While pyroxmangite is recognized from Broken Hill, all the specimens reported here have typical rhodonite compositions and properties.

Figure 13. Situated among the inclusions of sphalerite in specimen 8 was a euhedral negative crystal of rhodonite. Photomicrograph by Paul Millstead.



This study identified a diverse group of inclusions in transparent gem rhodonite from the North mine at Broken Hill. Previous studies of gem rhodonite from this locality (Diehl and Berdesinski, 1970; Bank et al., 1973a,b and 1974; Gaines et al., 1997) have not mentioned the presence of inclusions.

The basic gemological properties of Brazilian rhodonite appear to be comparable to those of rhodonite from Broken Hill. Faceted rhodonite from Minas Gerais, Brazil, was recently found to contain curved needles, “fingerprints,” and two-phase inclusions (Quinn, 2004), but no solid inclusions were identified.

We believe that the inclusions in the Broken Hill rhodonite originate from metamorphic reactions that may have produced fluids through processes of dehydration and decarbonation (Stevenson and Martin, 1986). It is probable that partial melting and plastic flow of the sulfides occurred in the Broken Hill ore deposit during peak metamorphism (Maiden, 1976), which may be evidence of high-temperature fluid activity (Plimer, 1979).

Experimental studies of the PbS-FeS-ZnS-Ag<sub>2</sub>S system by Mavrogenes et al. (2001) showed that eutectic melting of sulfide occurs between 772° and 830°C. In the Broken Hill region, metamorphism was accompanied by folding, which changed the original structure, texture, and mineralogical content of the Broken Hill ore deposit. While the sulfide minerals galena and sphalerite have an average grain size of 3–4 mm (Birch, 1999), microscopic pyrrhotite and other sulfide inclusions have also been trapped within the silicate mineralogy, including gem rhodonite. The presence of pyrrhotite in rhodonite supports the eutectic peak metamorphic conditions discussed.

The three-phase (saline liquid, CH<sub>4</sub>-N<sub>2</sub> vapor, and ilmenite crystal) inclusions are considered



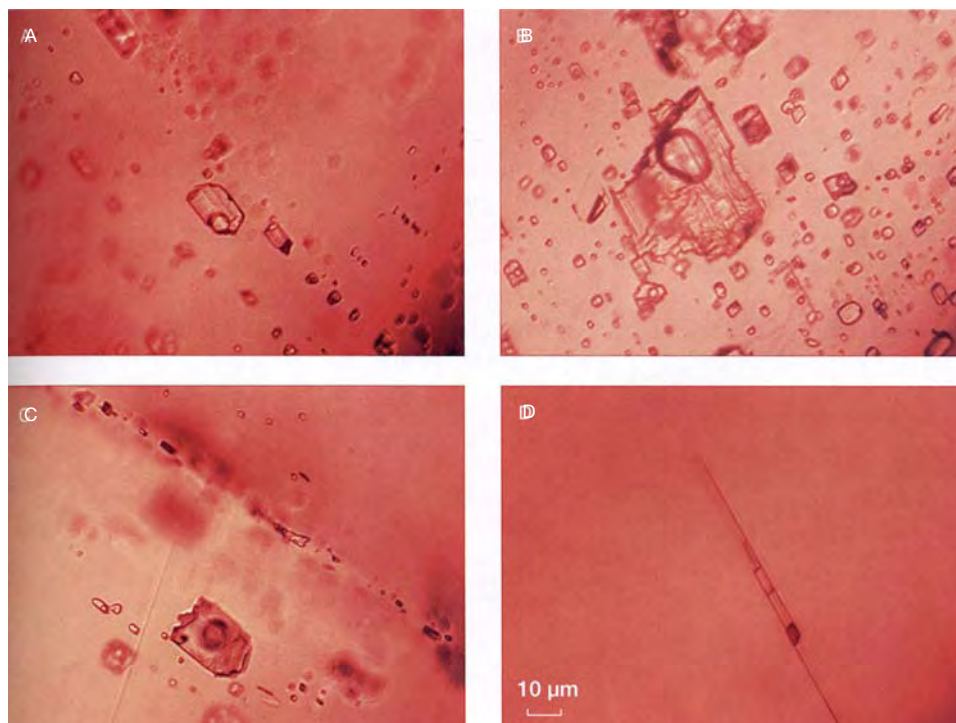


Figure 14. Specimen 4 contained numerous euhedral negative crystals with three phases: an ilmenite crystal, a saline liquid, and a  $\text{CH}_4\text{-N}_2$  vapor. Photomicrographs by Paul Millsted.

pseudosecondary. The binary mixture of  $\text{N}_2$  and  $\text{CH}_4$  in the vapor phase is in good agreement with previous studies of gases trapped in fluid inclusions from the gneissic host rocks and quartz veins of the Broken Hill ore deposit (Wilkins and Dubessy, 1984). The presence of inclusions of quartz, sub-angular elongate galena and sphalerite, and euhedral negative crystals of rhodonite

with sphalerite may be characteristic of Broken Hill gem rhodonite. In addition, analysis of the fluid inclusions in gem rhodonite may indicate whether or not they originated from the Broken Hill orebody. Further research on inclusions in rhodonites from this and other localities is needed to make a definitive determination in this regard.

Figure 15. Raman spectroscopy of the vapor phase of the three-phase fluid inclusion in crystal specimen 4 confirmed the presence of  $\text{N}_2$  and  $\text{CH}_4$ .  $\text{CO}_2$ ,  $\text{O}_2$ , and  $\text{H}_2\text{S}$  were below the detection limits.

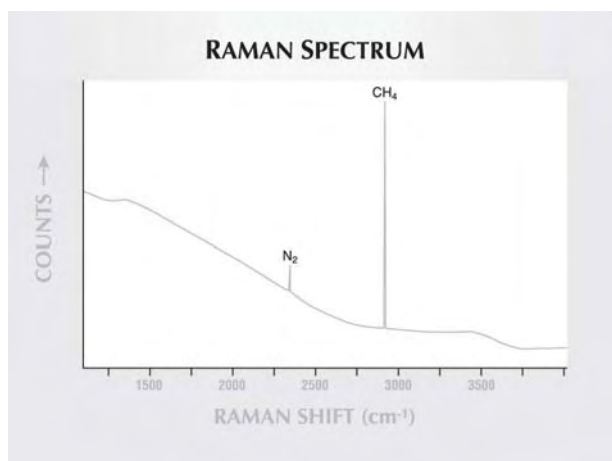
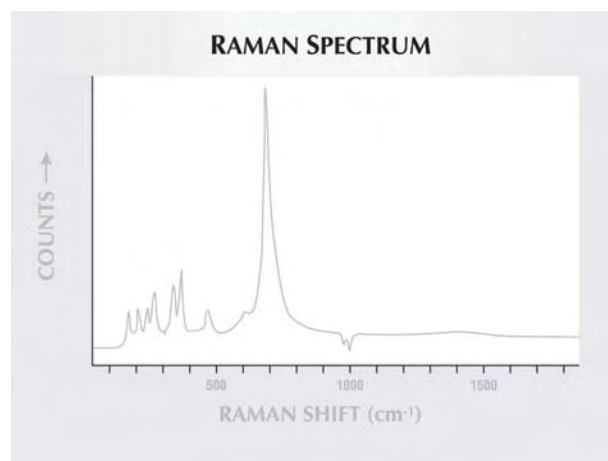


Figure 16. Raman spectroscopy also confirmed the presence of ilmenite crystals in a fluid inclusion in specimen 4, as illustrated in figure 14A. (The host rhodonite spectrum has been subtracted out, creating some “negative” peaks.)



## CONCLUSIONS

Sphalerite, galena, quartz, fluorite, and rare grains of pyrrhotite have been identified as solid inclusions in gem rhodonite from the Broken Hill area in New South Wales, Australia. Also identified for the first time in this material is a suite of three-phase (fluid, vapor, and solid) inclusions. These inclusions have trapped the products of dehydration, decarbonization, and partial melting during

metamorphism at Broken Hill, forming (in partially healed fractures) after the rhodonite crystallized. The rhodonite crystals also contained hollow needle-like tubes, as no solids, liquids, or gases were detected in these features by Raman analysis. The solid and three-phase inclusions may serve as clues to the evolutionary metamorphic processes and help identify gem rhodonite as being from the Broken Hill deposit.

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**Unusual SYNTHETIC ALEXANDRITE**

Magnification is traditionally the key method in the separation of natural and synthetic gemstones. Standard gemological tests such as refractive index, optic character, optic figure, and pleochroism are generally not useful in making this separation, since—by definition—to be a synthetic, a stone must have essentially the same optical, chemical, and physical properties as its natural counterpart. In some cases, however, the internal scene can be very misleading, so more advanced tests are necessary to prove natural or synthetic origin.

Recently, a 4.62 ct transparent blue-green oval modified brilliant (11.04 × 8.99 × 6.32 mm) was submitted to the East Coast laboratory for identification. The specimen exhibit-

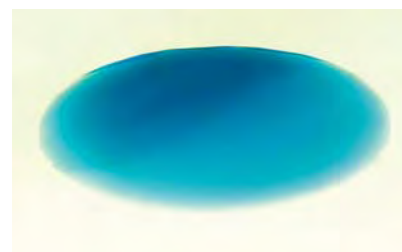
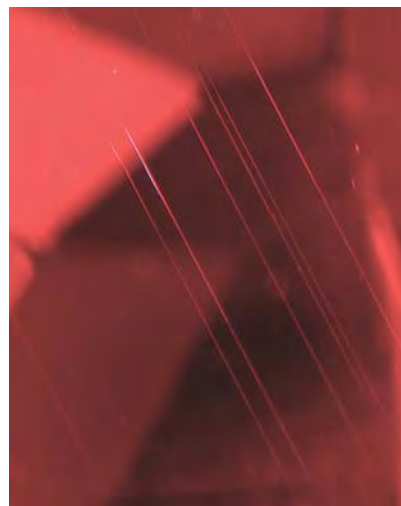
*Figure 1. It is very unusual to see crystals or negative crystals such as these in a melt-grown synthetic alexandrite. Note the three minute gas bubbles hovering above the crystals. Magnified 95×.*



ed a change of color to purple when viewed with incandescent (2800K) light. Standard gemological testing narrowed the sample's identity to either natural or synthetic alexandrite.

Magnification revealed a few tiny, high-relief, euhedral crystals or negative crystals (figure 1). Fiber-optic light further revealed many very fine, long, parallel needles (figure 2) among what appeared to be numerous tiny scattered, high-relief gas bubbles (again, see figure 1). This was puzzling, as neither crystals/negative crystals nor long needles are commonly associated with synthetic alexandrite, but the presence of free-floating gas bubbles would indicate

*Figure 2. These very fine, long, parallel needles were another unusual feature in the melt-grown synthetic alexandrite. Magnified 55×.*



*Figure 3. Subtle S-shaped curved growth zoning was evident in diffuse transmitted fluorescent light when the 4.62 ct synthetic alexandrite was immersed in methylene iodide.*

that the gem was a melt-grown synthetic. Unfortunately, the “gas bubbles” were so small that their identity could not be confirmed with a gemological microscope; it was possible that they were simply minute included crystals.

To observe the growth structure, we immersed the sample in methylene iodide and viewed it in diffuse transmitted light. As evident in figure 3, a very subtle S-shaped curved growth zoning was present. This, too, was indicative of a melt synthetic.

*Editor's note: The initials at the end of each item identify the editor(s) or contributing editor(s) who provided that item. Full names are given for other GIA Laboratory contributors.*

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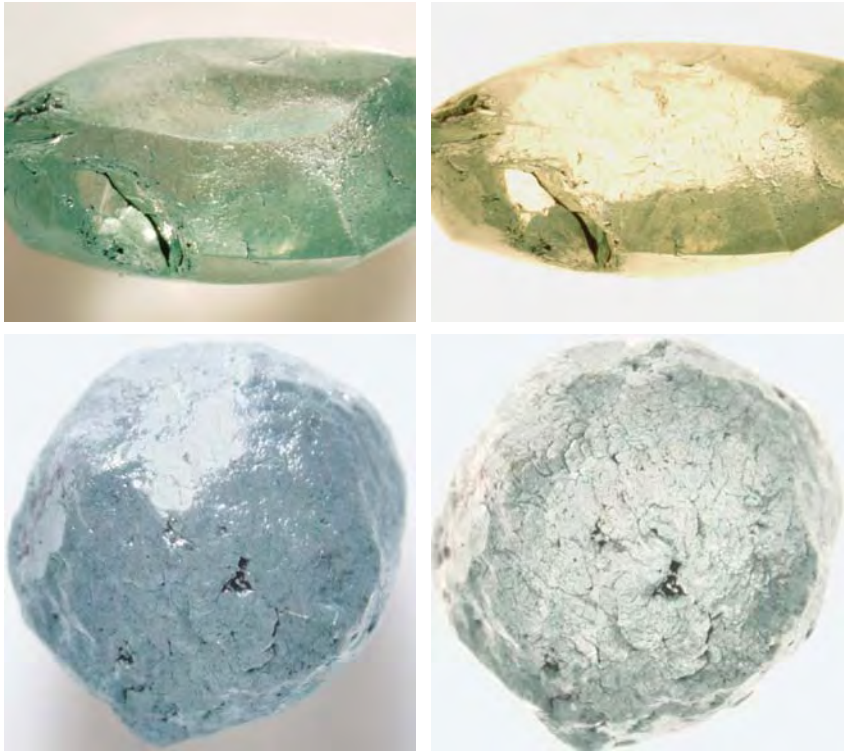
These conflicting observations meant that more-sophisticated testing was necessary to complete the identification. Infrared spectroscopy confirmed that the gem was synthetic alexandrite. This was not unexpected: The Spring 1993 Lab Notes (p. 46) also reported on a 3.59 ct synthetic alexandrite with numerous pinpoints (perhaps the gas bubbles we observed here) and short, scattered needle-like inclusions, as well as “slightly curved color banding” that appeared asymmetric. That sample also lacked water-related absorption bands in its infrared spectrum, consistent with a melt-process synthetic.

Over the years, we have seen a number of synthetic alexandrites with the uncommon combination of tiny gas bubbles and minute scattered randomly oriented needle-like inclusions. This most recent specimen was unique in that the needles were extremely long and parallel, a sight more commonly seen in natural stones. However, the infrared spectrum of this sample was similar to the spectra of those synthetic alexandrites we had examined previously. As evidenced in this case, IR spectroscopy can be a very important tool in the separation of natural from synthetic alexandrite, and in some cases it may be the only way to unequivocally prove a sample’s identity.

*Wendi M. Mayerson and  
David Kondo*

## DIAMOND Dyed Rough

The East Coast laboratory is occasionally asked to examine diamond rough prior to cutting. Recently, we received two diamond crystals, both with requests to determine whether their color was natural or the result of treatment. One crystal was approximately half a carat, and the second was about one carat. Both had worn edges and generally frosty surfaces with small, evenly distributed, crescent-shaped fractures and a few larger indentations. In reflected light, the smaller crystal appeared to be blue-green (fig-



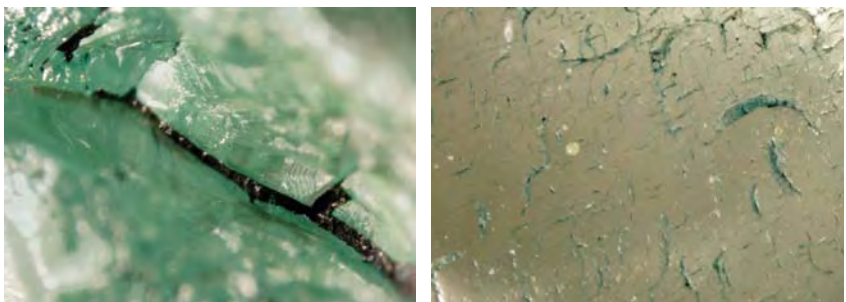
*Figure 4. These diamond crystals were submitted to the East Coast laboratory for origin-of-color determinations. Although the approximately half-carat diamond appeared blue-green when examined in reflected light (top left), transmitted light revealed its true yellow bodycolor (top right). The approximately 1 ct crystal appeared blue in reflected light (bottom left), while in transmitted light it was greenish gray (bottom right).*

ure 4, top left), while the larger crystal was blue (figure 4, bottom left).

Our suspicions were first raised when the smaller stone was viewed in transmitted light and a pale yellow

bodycolor was evident (figure 4, top right). On close inspection of the crystal surface, we noted a black to dark green flaky material in the largest indentation (figure 5, left), as well as

*Figure 5. At higher magnification, the smaller diamond crystal showed dye concentrations in indentations and cracks across its surface. A large indentation contained a dark flaky dye (left), while crescent-shaped cracks also contained concentrations of color (right). Magnified 40× (left), 20× (right).*



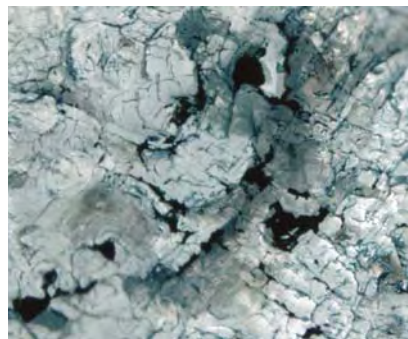


Figure 6. The larger rough diamond also showed dye concentrations on its surface. The small indentations contained a dark blue flaky dye, the shallow cracks contained lighter blue dye concentrations, and spots of an even lighter blue were seen on the surface itself. Magnified 45 $\times$ .

green concentrations in the shallow crescent-shaped cracks (figure 5, right).

When this crystal was examined with a desk-model spectroscope, it exhibited classic cape series absorption features (a line at 415 nm due to the N3 center, along with an N2 peak at 478 nm). As a result, we concluded that this particular piece of diamond rough was naturally yellow but had been surface dyed to produce an apparent blue-green color.

The larger crystal also exhibited different colors in reflected and transmitted light: It appeared blue in reflected light, but greenish gray in transmitted light (figure 4, bottom right). Indentations in the crystal surface contained a dark blue flaky material, shallow surface fractures exhibited concentrations of blue color, and lighter blue spots were seen on the surface of the rough (figure 6). When examined with a desk-model spectroscope, the larger crystal exhibited only a weak absorption feature at 415 nm. These observations were consistent with the larger crystal being gray to near colorless with a blue surface dye. Undoubtedly, in both cases, the dyed surface would have been removed during faceting.

Many gem materials are routinely dyed to alter or improve their color



Figure 7. These two strongly colored Fancy Deep blue diamonds (0.71 ct, left; 1.04 ct, right) showed some unusual characteristics in addition to their color.

appearance, but dyed diamond rough is unusual. In fact, this is the first report of such rough to appear in *Gems & Gemology*. These specimens are another reminder that simple "traditional" treatment methods, such as dyeing and coating (see, e.g., D. J. F. Evans et al., "Coated pink diamond—A cautionary tale," Spring 2005 *Gems & Gemology*, pp. 36–41), should not be forgotten when determining the origin of a diamond's color, whether polished or rough.

Carolyn van der Bogert

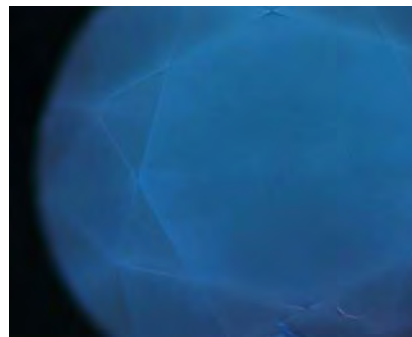
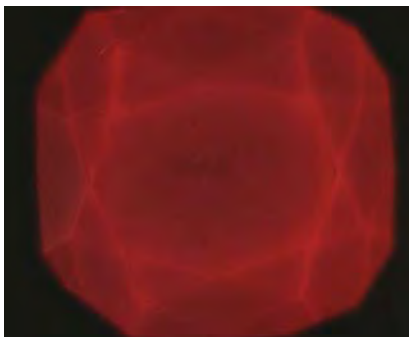
### Strongly Colored Natural Type IIb Blue Diamonds

Natural blue diamonds are among the rarest of all fancy-color diamonds. It is even rarer for type IIb boron-containing diamonds to be rel-

atively dark and strongly colored (see J. King et al., "Characterizing natural-color type IIb blue diamonds," Winter 1998 *Gems & Gemology*, pp. 246–268). Recently, the East Coast laboratory had the opportunity to examine two Fancy Deep blue diamonds, a 0.71 ct octagonal brilliant and a 1.04 ct round brilliant. As can be seen in figure 7, both displayed strong blue color. Gemological and spectroscopic tests performed on these diamonds yielded some interesting observations.

When examined with magnification, these two diamonds revealed few internal features beyond scattered pin-points and needles, with no color zoning evident. Both had very high electrical conductivity, as would be expected for type IIb diamonds. Fluorescence was very weak yellow to

Figure 8. After exposure to strong short-wave UV radiation in the DiamondView, the diamonds in figure 7 displayed strong phosphorescence. The intense red reaction of the 0.71 ct stone is among the strongest ever seen at the GIA Laboratory.



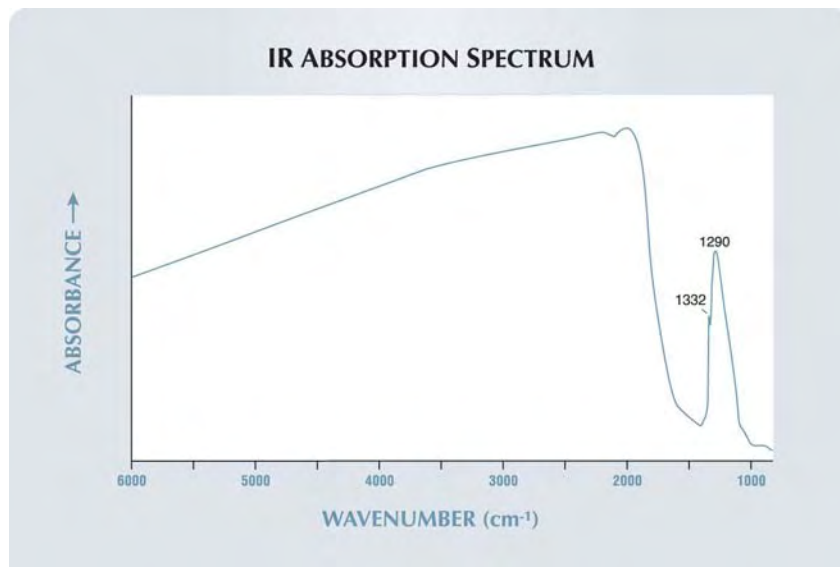
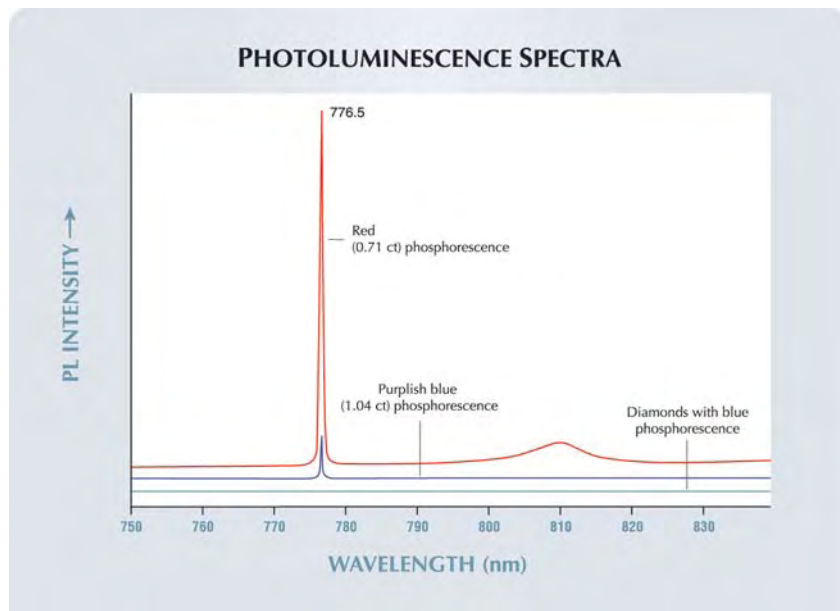


Figure 9. The mid-IR spectrum of the 1.04 ct round brilliant shows complete saturation in the region of the boron features, reflected in the near-total absorption above  $\sim 2000\text{ cm}^{-1}$ . Also present is the  $1332\text{ cm}^{-1}$  intrinsic diamond peak; the assignment of the peak at  $1290\text{ cm}^{-1}$  is unknown.

Figure 10. The PL spectra of the two diamonds reflect the relative strength of their red phosphorescence. The emission peak at  $776.5\text{ nm}$  for the 0.71 ct octagonal brilliant, with its strong red reaction, is of greater intensity than that for the 1.04 ct round brilliant (with its weaker purplish blue phosphorescence). The spectrum of a diamond with blue phosphorescence usually does not show  $776.5\text{ nm}$  emission. (The diamond Raman peak at  $1332\text{ cm}^{-1}$ , which occurs in the PL spectrum at  $521.9\text{ nm}$ , is normalized to the same intensity for the three spectra.)



inert to both long- and short-wave UV radiation from a handheld lamp.

Both diamonds displayed unusual phosphorescence (figure 8) after observation in the DTC DiamondView, which employs strong short-wave UV radiation. While the 1.04 ct diamond showed moderately strong purplish blue phosphorescence, the 0.71 ct stone displayed some of the most intense red phosphorescence that we have ever observed. This color reaction to the short-wave UV of the DiamondView in natural type IIb diamonds is rare, just as it is for a handheld lamp (again, see King et al., 1998). One well-known example of red phosphorescence is the Hope diamond (see R. Crowningshield, "Grading the Hope diamond," Summer 1989 *Gems & Gemology*, pp. 91–94).

The mid-infrared absorption spectrum of the 1.04 ct stone revealed some very unusual features. Due to a very high concentration of boron, absorption above  $2000\text{ cm}^{-1}$  was so strong that the spectrum was entirely "saturated" (figure 9). Photoluminescence (PL) spectroscopy, collected using Ar-ion laser ( $488\text{ nm}$ ) excitation, showed a very strong emission at  $776.5\text{ nm}$  in the 0.71 ct stone (figure 10). In the 1.04 ct stone, this emission was distinct but much weaker in intensity. Natural type IIb diamonds with the more common blue phosphorescence usually do not show this emission. These observations indicate a possible genetic relationship between the  $776.5\text{ nm}$  emission and red phosphorescence.

*Paul Johnson and Kyaw Soe Moe*

## PEARLS

### Large Natural Freshwater Pearl from Texas

The GIA Laboratory has previously reported on natural pink freshwater pearls from the Concho River northwest of Austin, Texas (Summer 1989 *Gem News*, p. 115), and the lakes and rivers in the San Angelo area of west Texas (Fall 1990, pp. 223–224). Recently, another attractive pink



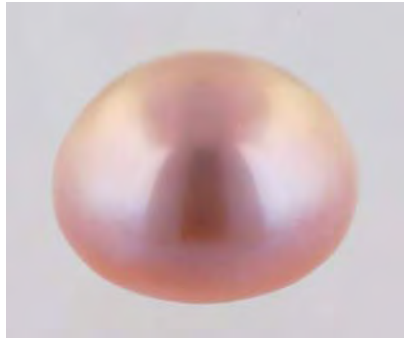


Figure 11. This 8.48 ct natural pink button pearl was reportedly found in a three-ridge mussel in a tributary of Lake Nasworthy, San Angelo, Texas.

pearl from Texas arrived at the West Coast laboratory for identification. The button-shaped pearl (figure 11) measured approximately  $11.60 \times 8.70$  mm. The clients, Bill and Chase Holland of Holland Jewelry Company, San Angelo, stated that with the dwindling populations of mussels in west Texas, pearls of this type over 5 mm are very rare. Mike Bagwell and Susan Martin recovered the pearl from a three-ridge mussel (*Amblema plicata*, also called blue-point, purple-tip, or fluter) in a spring-fed creek that supplies Lake Nasworthy, a reservoir in San Angelo. Branches of the Concho River, the source for many of the pink mussel pearls previously reported, also meet at Lake Nasworthy. Although the three-ridge mussel is common in some parts of the Midwest and southern United States, their populations are depleted in west Texas; according to Mr. Bagwell, they only exist in areas of continual stream flow.

Magnification of the pearl confirmed the client's statement that it had been buffed, enhancing its luster. The X-radiograph showed natural structure, and the X-ray fluorescence was weak yellow on the crown and medium to strong yellow on the lighter-colored base. Long-wave UV fluorescence was medium to strong blue. Energy-dispersive X-ray fluorescence (EDXRF) analysis performed by

research gemologist Shane Elen revealed a very low Mn content. Although the Mn content alone was not enough to confirm that the pearl originated in freshwater, this pearl was reportedly from a known source, and the pink color along with the distinct fluorescence to X-rays were enough to substantiate the freshwater origin.

The Tampico pearly mussel (*Cyrtornaias tampicoensis*) and the Bleufer unionid (*Potamilus purpuratus*) are two other nacreous mussels that are known to produce pearls of this color in the southern U.S., including Texas, but this is the first pearl of such fine color and large size we have seen that is reported to be from a three-ridge mussel in Texas.

CYW

#### Natural Pearl, with a "Round" Core, which Appears Cultured

Sometimes natural features seen in pearl X-radiographs so closely resemble those of cultured pearls that even experienced gemologists must scruti-

Figure 12. The pearl ( $12.5 \times 11.10 \times 10.60$  mm) in this necklace contained a natural core that, on the X-radiograph, initially looked like a bead nucleus.



nize the details very carefully to avoid a misidentification. The pearl necklace in figure 12 proved to be such a challenge. The initial X-radiograph showed a "spherical" feature in the pearl's core that at first glance appeared to be a bead nucleus (figure 13, left). Although natural growth structures were present in the core (figure 13, right), they were faint on the X-radiograph and would not have been obvious to the untrained eye. A close look also revealed that the central sphere was slightly darker in tone than the outer nacre layers (again, see figure 13), which is an indicator of natural origin (freshwater shell-bead nuclei typically present themselves on an X-radiograph as slightly lighter than the surrounding pearl nacre). However, since the center appeared to be both nearly perfectly round and separated from the surrounding nacre, additional radiographs were necessary to identify its exact nature.

Another radiograph, taken  $90^\circ$  to the first, revealed that the core was in fact slightly asymmetrical and ovate in shape (figure 13, center). The variance in the shape of the core, its slightly darker appearance, and the natural growth structures confirmed this to be a natural pearl. The apparent detachment of the core from the outer nacre resulted from layers of conchiolin being deposited between the center and outer nacre layers. This, along with the round profile of the core on the first radiograph, produced an initial appearance that could have been confused with a cultured pearl.

The GIA Laboratory often receives pearl inquiries accompanied by X-radiographs that were taken by staff members of dental, medical, or veterinary offices, with subsequent identifications frequently attempted by those staff members, the client, or a retail jeweler. This pearl confirms that initial observations, if not conducted and carefully scrutinized by experienced gemologists with the proper equipment, can result in a misidentification.

CYW



Figure 13. The first X-radiograph of the pearl in figure 12 exposed what appeared to be a spherical core that is slightly darker than the outer nacre layers (left). Another radiograph taken 90° to the first revealed a slightly asymmetrical oval outline (center) and natural features (right).

### Large Baroque “Golden” South Sea CULTURED PEARLS

The East Coast laboratory recently received for identification a pair of large undrilled baroque South Sea cultured pearls, which were subsequently set in yellow metal earrings (figure 14). One cultured pearl measured approximately 24.85 × 17.95 × 13.60 mm and weighed 38.30 ct; the second measured approximately 24.50 × 18.90 × 16.15 mm and weighed 40.55 ct. These South Sea cultured pearls were notable for their size and quality as well as for being relatively well matched, especially for baroque pearls.

There was a slight difference in color between the two. In addition, the bodycolor of each individual cultured pearl was variegated, as is often the case with baroque pearls. In the GIA Pearl Description System, a color designation represents a range of color sensations, and a grade is assigned based on the overall color appearance when observed under standardized lighting and viewing conditions. The color of these cultured pearls fell into the range described as *yellow*, but commonly referred to in the trade as “golden.” Both cultured pearls had very good luster and appeared only lightly blemished for baroque pearls.

In addition, orient (an iridescent play of color within the nacre) was present on both.

Testing proved these to be naturally colored bead-nucleated cultured pearls. X-radiography revealed the presence of bead nuclei with varying nacre thicknesses. Long-wave UV fluorescence ranged from chalky slightly greenish yellow to deeper orangy yellow, both of which are consistent with natural color. In addition, visible-range spectroscopy was suggestive of natural color origin (see, e.g., S. Elen, “Spectral reflectance and fluorescence characteristics of natural-color and heat-treated ‘golden’ South Sea cultured pearls,” Summer 2001 *Gems & Gemology*, pp. 114–123).

Akira Hyatt

Figure 14. These large baroque South Sea cultured pearls (38.30 and 40.55 ct) are unusual for their size and quality.



### SYNTHETIC TURQUOISE Necklace

Introduced to the industry in 1972, Gilson synthetic turquoise can be recognized by its characteristic “cream of wheat” texture, which appears with magnification as bluish spheroids in a light colored groundmass (figure 15, left). Although distinctive to most gemologists, it is not dramatically different from the texture seen in some natural turquoise (figure 15, right), the difference being more in the uniformi-

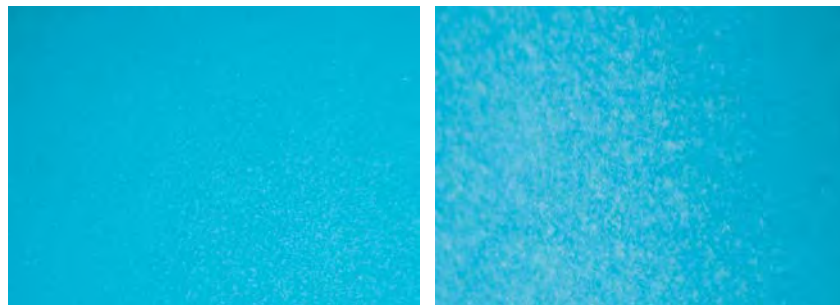


Figure 15. Gilson synthetic turquoise (left) shows a characteristic “cream of wheat” texture. Although the texture of natural turquoise (right) can sometimes be similar, there are subtle differences in uniformity of structure. Magnified 20 $\times$ .

ty of the structure. This texture is an excellent example of a property that can best be described as “similar, but different” from its natural counterpart.

Recently, a graduated strand of 45 round greenish blue beads (14–16 mm) was submitted to the West Coast laboratory for identification (figure 16). The

spot refractive index of the beads tested was 1.60, and microscopic examination showed the classic “cream of wheat” texture associated with Gilson synthetic turquoise. To confirm this initial identification, a small amount of the material was scraped from near the drill hole of a single bead and analyzed

Figure 16. This graduated strand of 45 round greenish blue beads (14–16 mm) proved to be synthetic turquoise.



using mid-infrared spectroscopy. Although both natural and synthetic turquoise have many of the same spectroscopic features, the peaks in the spectrum for synthetic turquoise (figure 17) are smoother due to a different state of aggregation (M. Arnould and J.-P. Poirot, “Infra-red reflection spectra of turquoise (natural and synthetic) and its substitutes,” *Journal of Gemology*, Vol. 14, 1975, pp. 375–377; G. Rossman, “Color in gems: The new technologies,” Summer 1981 *Gems & Gemology*, pp. 60–72).

Infrared spectroscopy confirmed that the necklace was indeed composed of synthetic turquoise. The challenge in identifying the material, however, is not what makes this piece unique. While we have seen synthetic turquoise on occasion in the past, it has always been as individual pieces and carvings. This is the first time we have seen an entire necklace of matched and graduated synthetic turquoise beads of this quality and size.

Kimberly Rockwell

#### YTTTRIUM ZIRCONIUM OXIDE

The West Coast laboratory received a 19.66 ct (15.04  $\times$  12.93  $\times$  8.40 mm) intensely colored greenish blue gem for identification (figure 18). At first glance, it had the appearance of a zircon but lacked zircon’s high dispersion. With the exception of an extremely fine particulate cloud throughout (that was only visible due to the white Tyndall scattering it produced), the stone was free of inclusions. It was over the limits of a standard refractometer and singly refractive; the polariscope showed anomalous double refraction with weak cross-hatch and snake-band effects. The long-wave UV fluorescence was a somewhat chalky weak to medium green-yellow; the short-wave reaction was very chalky medium orange. The spectrum visible in the desk-model spectroscope showed doublets at approximately 520, 540, and 595 nm, with a fluorescent band between the lines of the 540 nm doublet. There was



a dark band at approximately 640 nm with a cutoff around 660 nm. Several additional weak lines were visible between the doublets. The abundance of bands in this region of the spectrum indicated the possible presence of one or more rare-earth elements. The S.G. was 5.57, which was just below the lower "limit" of cubic zirconia (CZ).

To characterize this specimen further, we performed Fourier-transform infrared (FTIR) and Raman spectroscopy. The FTIR spectrum was similar to that of another sample that we had previously identified as CZ. The Raman spectrum most closely matched the reference spectrum for CZ in the database, which had some peaks in similar locations to those of the sample. However, the peak heights varied, and the match was tenuous.

Although the sample appeared to be CZ, it required EDXRF analysis to confirm the identification. Zirconium was indeed a major element, but the

qualitative data suggested that yttrium, which is used to stabilize manufactured CZ at room temperature, was present in what appeared to be a greater quantity than Zr. There was also a trace of hafnium. CZ typically contains significantly less Y than Zr, which raised the question of whether this was CZ with a large amount of stabilizer, or another material altogether. Analysis of phase diagrams (e.g., R. Roth et al., *Phase Diagrams for Ceramists*, American Ceramic Society, Columbus, Ohio, 1981, Vol. 4, pp. 141–142 and 1987, Vol. 6, pp. 182–184), as well as various texts (e.g., K. Nassau, *Gems Made by Man*, Chilton Book Co., Radnor, PA, 1980, p. 240) indicated that in fact CZ can contain slightly more yttrium than zirconium.

The possibility that our sample might be one of these CZs with excessive stabilizer was supported by a further literature search, which indi-



Figure 18. Resembling a high-quality zircon, this intensely colored greenish blue gem (19.66 ct) is a manufactured product, yttrium zirconium oxide.

cated that the deep blue and green colors are accomplished by adding large amounts of stabilizers (see Winter 1983 Lab Notes, pp. 232–233; K. Nassau, "Synthetic gem materials in the 1980s," Spring 1990 *Gems & Gemology*, pp. 50–63). Some types of "highly stabilized CZ" were manufactured in the early 1980s under the trade name "C-Ox." Although it is likely that our sample was the same or a similar product, we were unable to prove this. The absorption bands in our visible spectrum did not exactly match those published for C-Ox, but the difference might be explained by the variance in color and the corresponding chromophore(s) used. In addition, the exact chemical boundaries of manufactured CZ are not well defined, so it was still difficult to know if a sample with such a high yttrium content could still be properly called CZ. Therefore, the laboratory identified the material by the chemical compound name, yttrium zirconium oxide.

CYW and Sam Muhlmeister

Figure 17. The mid-IR spectral features of natural turquoise are noticeably sharper than those for the synthetic material. Spectra have been offset for clarity. (Modified from E. Fritsch and C. Stockton, "Infrared spectroscopy in gem identification," Spring 1987 *Gems & Gemology*, p. 22.)

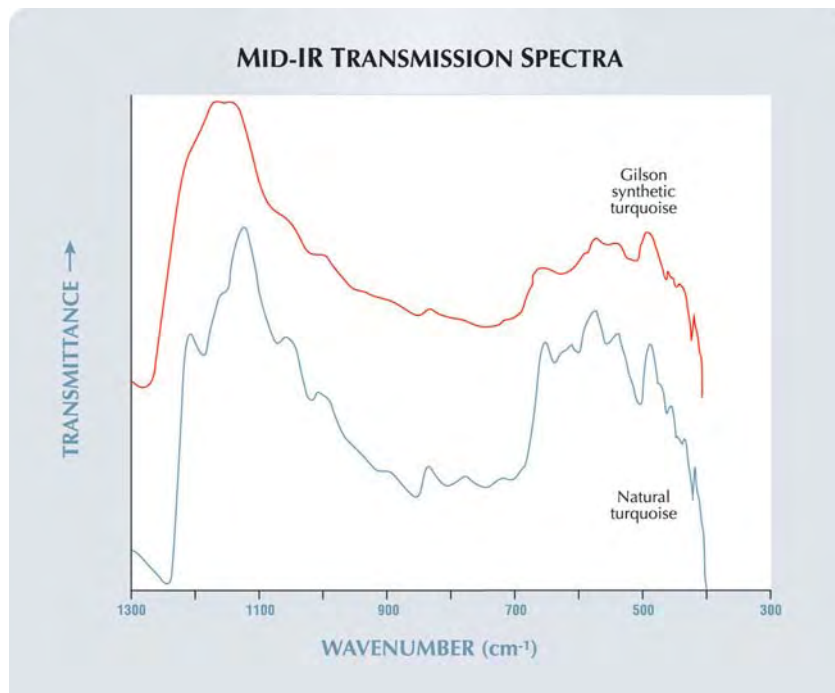


PHOTO CREDITS

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## DIAMONDS

**Gem mosaics of faceted diamonds.** Mosaic artwork constructed from gem materials has typically used rough fragments or tumbled/polished pieces of colored stones. However, until now this contributor was unaware of the use of faceted fancy-color diamonds to create gem mosaics. During a recent trip to Brazil, several examples of this new artwork, referred to as Diamond Craft (figure 1), were shown to her by Jorge Brusa (Bristar, Sao Paulo).

Mr. Brusa began experimenting with the concept in

*Figure 1. This Diamond Craft gem mosaic after one of Vincent van Gogh's "Bedroom" paintings measures 10 × 10 cm and was created with 5,482 fancy-colored faceted diamonds, with a total weight of 46.32 ct. Courtesy of Bristar.*



2002. His first prototype consisted of placing the diamonds between glass and fabric and holding them together with a frame, but he experienced difficulties keeping the diamonds in place. In 2003, he experimented with securing the diamonds with a type of spackling paste, but that method also had problems. However, he recently developed a proprietary process that has proved successful in holding the stones.

To create the mosaics, the melee diamonds are carefully situated table-down on a piece of glass placed over the artwork. To date, eight different images have been used as models for the mosaics—two by Vincent van Gogh, one by Paul Klee, and five of his original designs. The diamonds consist of a mix of natural colors (yellows, browns, and near-colorless) and treated colors (pinks, blues, and greens), all purchased in India. Mr. Brusa indicated that the most difficult part is selecting diamonds that have a uniform depth, which is required for the process to work successfully.

The largest mosaic completed to date measured up to 13 × 10 cm before framing, and contained up to 10,800 diamonds with a total weight of 102 carats.

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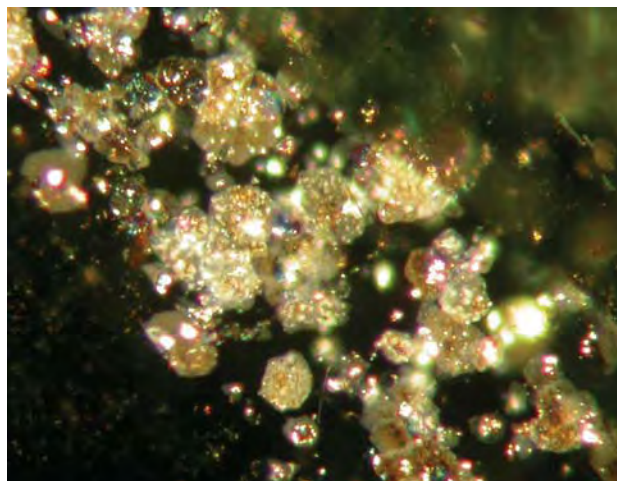
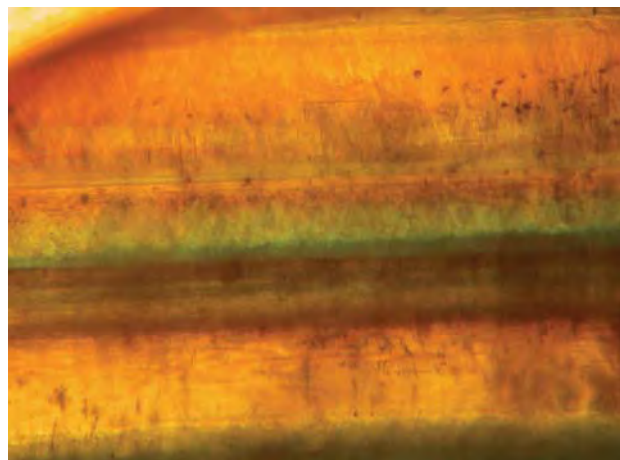
## COLORED STONES AND ORGANIC MATERIALS

**An unusual emerald with conical growth features.** Recently, a 5.37 ct emerald was submitted to the Gem Testing Laboratory in Jaipur, India, for identification. Initial observation with a gemological microscope showed strong color zoning in parallel layers, and some of the planes contained conical growth features that resembled those seen in hydrothermal synthetic emeralds. This prompted a more detailed examination of the sample.

Refractive indices taken from the table, crown, and pavilion facets yielded similar values, between 1.580 and 1.590, with a birefringence of 0.008–0.009. Specific gravity (measured hydrostatically) was 2.72. This S.G. is consistent with the values reported for natural and hydrothermal synthetic emeralds, but the refractive indices were slightly higher than those for hydrothermal synthetics and some natural emeralds (see, e.g., J. I. Koivula et al., "Gemological investigation of a new type of Russian hydrothermal synthetic emerald," Spring 1996 *Gems & Gemology*, pp. 32–39).

Microscopic examination revealed "fingerprints" and scattered whitish clouds of crystals that crossed the color and growth zones. Similar features also were observed in some Russian hydrothermal synthetic emeralds by Koivula et al. (1996), although they were of a reflective nature, while the particles reported here typically appeared sugary. To better observe the growth features, we immersed the sample in bromoform. Conical growth features were seen along almost all the boundaries between the green and colorless zones (figure 2). However, the individual cones were not restricted to a single plane, and they varied in size. None of the chevron-type growth patterns that are characteristic of

*Figure 2. Microscopic examination of a 5.37 ct emerald showed alternating color bands with subtle conical growth features on the edges of the color zones. Photomicrograph by G. Choudhary; magnified 35×.*



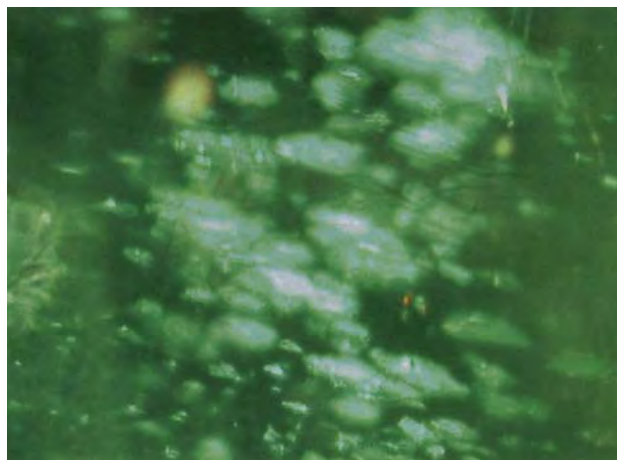
*Figure 3. Planes of brownish hexagonal iridescent plates also were seen in the unusual emerald. Photomicrograph by G. Choudhary; magnified 40×.*

hydrothermal synthetic emerald were observed in the stone.

With fiber-optic light, the emerald exhibited a sheen effect caused by iridescent, roughly hexagonal platelets that formed along planes in the green color zones near the colorless boundaries (figure 3). By comparison, a few black opaque hexagonal plates (not iridescent) were reported in Russian hydrothermal synthetic emeralds by Koivula et al. (1996). In certain orientations (i.e., nearly parallel to the color bands), the platelets documented in the present stone appeared silvery and reflective (figure 4). Such inclusions have not been reported previously in any natural or synthetic emeralds.

FTIR spectra taken in various directions all exhibited a pattern indicative of natural emerald (figure 5). Compared

*Figure 4. When viewed in certain orientations in darkfield illumination, the iridescent plates showed silvery reflections. Photomicrograph by G. Choudhary; magnified 45×.*





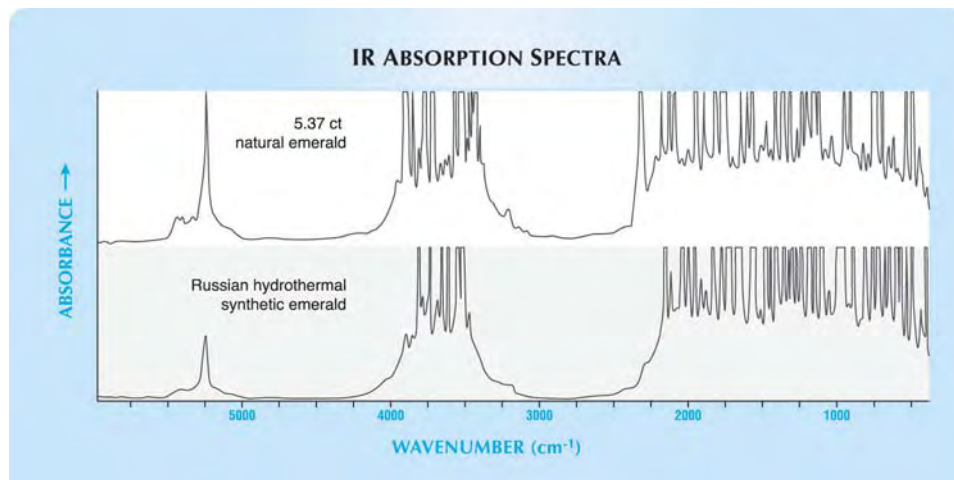


Figure 5. A comparison of the infrared spectrum of the 5.37 ct emerald with that of a Russian hydrothermal synthetic emerald shows differences in the absorption bands between 4000 and 3000  $\text{cm}^{-1}$  and in the intensity of the peak at around 5270  $\text{cm}^{-1}$ . The IR absorption features shown by the 5.37 ct emerald are indicative of natural origin.

to hydrothermal synthetic emeralds, there were significant differences in the intensity of the absorption features due to type II water between 4000 and 3000  $\text{cm}^{-1}$ . Another major difference was the intensity of the peaks at around 5270  $\text{cm}^{-1}$ , which were much stronger in the natural emerald reported here.

Although the stone contained some unusual internal features, the FTIR spectra led us to conclude that it was a natural emerald.

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Gem Testing Laboratory, Jaipur, India

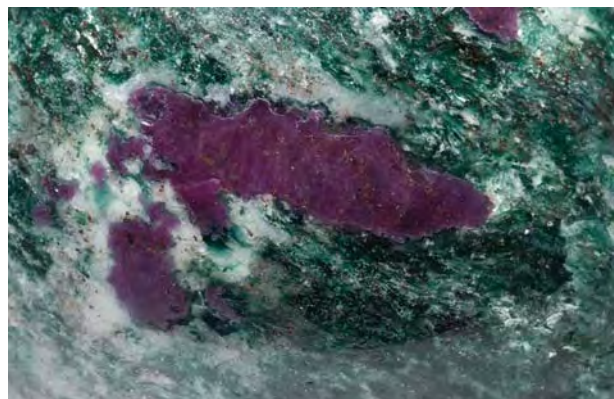
Figure 6. This sphere (5.4 cm in diameter) was cut from a rock consisting of fuchsite, corundum, and alkali feldspar. The material comes from a new deposit in Bahia, Brazil. Photo by C. D. Mengason; GIA Collection no. 32380.



**Fuchsite-corundum rock from Bahia, Brazil.** Green quartzite, or aventurine quartz, is widespread in the Precambrian terranes of Brazil. It is found in small deposits from the southern tip of Minas Gerais to northern Bahia and western Goiás. The material is composed mainly of fine- to coarse-grained quartz and fuchsite mica (chromian muscovite). The amount of fuchsite in the rock may be quite variable, from a few percent up to, rarely, 100%. Although the origin of these Cr-rich rocks is not yet well understood, it seems likely that they formed through the metamorphism of Cr-bearing sedimentary strata.

In January 2005, a new occurrence of fuchsite with corundum and feldspar was found near Serra de Jacobina, northern Bahia State. Preliminary characterization of several samples with a microscope and powder X-ray diffraction

Figure 7. A closer view of the sphere in figure 6 shows blebs of corundum (here, up to 1.9 cm wide) that are surrounded by intergrowths of fuchsite and alkali feldspar. Tiny grains of reddish orange rutile are disseminated throughout the rock and also form inclusions in the corundum. Photo by C. D. Mengason.



showed that the rock consists of coarse-grained fuchsite with blebs of opaque pinkish purple corundum and irregular pods and interstitial areas of white alkali feldspar (figure 6). Also present were tiny grains of reddish orange rutile (figure 7) that showed a submetallic luster. No quartz could be found in the rock. The various textures and color combinations created by the minerals are particularly attractive when polished into spheres (again, see figure 6).

The association of fuchsite and corundum, together with kyanite, is also known from India, Zimbabwe, and South Africa (see Winter 2004 Gem News International, pp. 338–339, and the reference therein). These mineral associations are formed by prograde metamorphism at high temperature and pressure. The formation of the Brazilian occurrence may be explained by the following reaction: mica  $\leftrightarrow$  corundum + feldspar + H<sub>2</sub>O. At the other occurrences, the initial presence of quartz may be responsible for the additional formation of kyanite in the rock: mica + quartz  $\leftrightarrow$  kyanite/corundum + feldspar + H<sub>2</sub>O.

So far, about 150 kg of the fuchsite-corundum rock have been recovered from the Brazilian deposit. The geology of the deposit suggests that additional production is likely in the future.

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**Pen shell pearls—nacreous and non-nacreous.** The Winter 2003 Gem News International section (pp. 332–333) reported on pen shell pearls from the Pacific Coast of Baja California, Mexico. Pen shells from this area (i.e., *Pinna sp.* and *Atrina sp.*) have a nacreous layer on their interior that grows on top of, and is distinctly different in composition from, the underlying non-nacreous portion of the shell. Because the bond between these layers is weak, they readily separate after the death of the mollusk (figure 8).

Since the pearly layer covers only part of the shell's interior, the mollusk could conceivably host a nacreous pearl and a non-nacreous concretion simultaneously within the same shell. A nacreous and a non-nacreous sample (2.29 and 17.83 ct, respectively) were recently donated to GIA by Jeremy Norris of Oasis Pearl, Albion, California (figure 9). Although they did not come from the same mollusk, both reportedly originated from the same species of Baja California pen shell, identified as *Pinna rugosa* by Mr. Norris and confirmed by consulting shell experts Scott Rugh (San Diego Natural History Museum) and Paul Valentich-Scott (Santa Barbara Museum of Natural History). As shown in the Winter 2003 GNI entry, nacreous pen shell pearls can be quite attractive, and although the non-nacreous “pearls” would not be suitable for jewelry use because of their tendency to dry out and crack over time, concretions such as these can make interesting collectors' items.

Further characterization with UV-Vis reflectance spectroscopy was performed on both samples and on the different sections of the pen shell supplied by Mr. Norris. The



Figure 8. The interior of the rugose pen shell (*Pinna rugosa*) from Baja California has a light-colored nacreous layer that readily separates from the non-nacreous dark brown base layer. This shell is approximately 35.5 cm long. Courtesy of Oasis Pearl; photo by C. D. Mengason.

spectrum for the nacreous pearl was distinctly different from that of the non-nacreous “pearl,” and their spectra were similar to those of the corresponding sections of the pen shell. Although the spectral data suggest that both samples originated from the pen shell, given the limited data available, further research is necessary to establish the significance of the spectral matches between the pearl/concretion and their respective portions of the shell.

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GIA Laboratory, Carlsbad

Figure 9. The light brown nacreous pearl on the left (7.8 × 6.9 × 5.6 mm) and the dark brown non-nacreous “pearl” on the right (17.3 × 13.5 mm) both originated in rugose pen shells from Baja California, Mexico. Their dissimilar appearance and structure is the result of growth in compositionally different sections of the host shells. GIA Collection nos. 31758 (pearl) and 31759 (concretion); photo by C. D. Mengason.







Figure 10. A new deposit in Tamil Nadu, India, is the source of these sapphires (0.36–2.01 ct). Courtesy of Dudley Blauwet Gems; photo by C. D. Mengason.

**New sapphires from Tamil Nadu, India.** In early August 2005, gem and mineral dealer Dudley Blauwet (Dudley Blauwet Gems, Louisville, Colorado) informed these contributors about a new find of pinkish orange to purple sapphires from India. According to his supplier, the material comes from the Kurur area of Tamil Nadu State, and much of it has been collected by farmers from near-surface secondary deposits. Mining has been hindered by the lack of available water to wash the soil, but rough parcels weighing 200–300 grams occasionally have been obtained by a few local dealers.

The rough is recovered as broken fragments, some of which are rather large (i.e., up to 12–20+ grams). However, most of the material is extensively fractured, so typically the cut stones weigh up to 1–3 ct. Nevertheless, the largest faceted stone that Mr. Blauwet was informed about weighed approximately 30 ct.

Most of the sapphire is found in shades of lavender and pink, and is heated to 1,100°C in Sri Lanka. The resulting coloration typically ranges from orange to amethyst-like

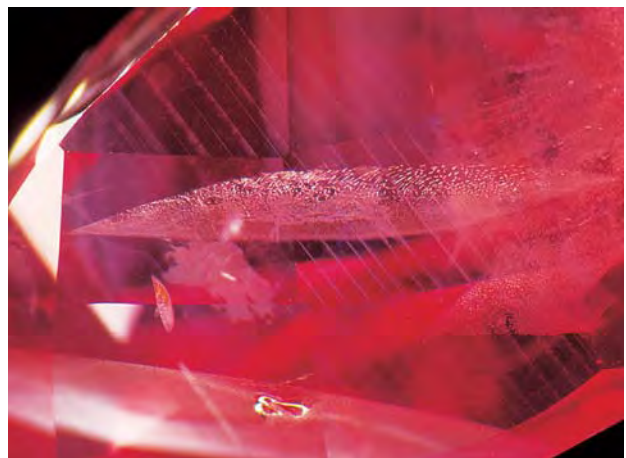
purple colors, commonly with strong color zoning (figure 10). The blue component has proved difficult to remove from the “silky” lavender rough, but heating to higher temperatures is avoided due to the risk of causing more fractures in the material.

Mr. Blauwet donated one unheated and two heated sapphires to GIA, and also loaned 14 heated sapphires for examination (0.36–3.87 ct). Gemological examination of six representative stones (0.36–1.70 ct) revealed the following properties: color—purplish pink to orangy pink, with one stone being a brownish pinkish purple and another being distinctly bicolored reddish purple and reddish orange face up; pleochroism—red-to-orange or red-to-purple; R.I.—1.760–1.769, with a birefringence of 0.008–0.009; and S.G.—4.0. When viewed with a gemological microscope, the samples displayed uneven coloration in zones or bands, as well as groups of short, fine rutile needles, fine-grained clouds (figure 11), lamellar clouds (figure 12), clouds of tiny reflective platelets sometimes interspersed with rutile needles (figure 13), and

Figure 11. Some of the sapphires from Tamil Nadu contained fine-grained clouds. Photomicrograph by S. F. McClure; magnified 17×.



Figure 12. This sapphire from Tamil Nadu contains lamellar clouds and conspicuous “fingerprints.” Photomicrograph by S. F. McClure; magnified 21×.





“fingerprint” inclusions. They exhibited weak-to-moderate red fluorescence to long-wave UV radiation, and weak red or no fluorescence to short-wave UV. Typical features seen with a desk-model spectroscope included a weak absorption band at 460 nm, a 475/480 nm doublet, and a band at 670 nm.

Although the colors of some of these samples resemble those seen in sapphires treated by Be diffusion, the samples showed no evidence of the high temperatures used in that process. According to Mr. Blauwet, much of this Indian sapphire is being sold on the market as heated Sri Lankan or Madagascar material.

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**Tenebrescent scapolite from Afghanistan.** At the 2004 Tucson Gem shows, gem and mineral dealer Herb Obodda (H. Obodda, Short Hills, New Jersey) showed GIA personnel several rough and cut pieces of a colorless gem material from Badakhshan, Afghanistan, that was thought to be hackmanite on the basis of its reversible photochromism (or tenebrescence, a property in which some minerals darken in response to radiation of one wavelength and then reversibly lighten on exposure to a different wavelength). When “charged” under Mr. Obodda’s strong UV source, the stones turned blue. When they were exposed to daylight or a strong incandescent light source, the color faded completely in seconds.

Mr. Obodda obtained the rough material during buying trips to Pakistan in early 2003 through early 2004. He said that the local dealers have habitually referred to the colorless sodalite from Badakhshan as “hackmanite”—

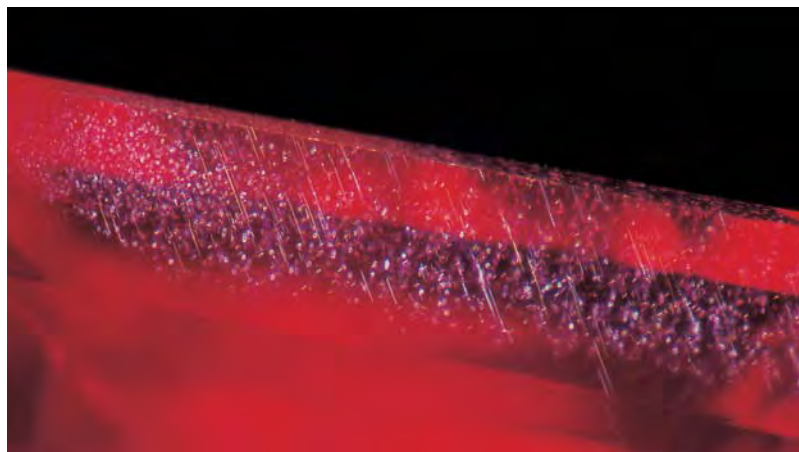


Figure 13. Clouds of tiny reflective platelets and short rutile needles are seen in this Tamil Nadu sapphire. Photomicrograph by S. F. McClure; magnified 37 $\times$ .

even though they were unaware that any of the pieces showed tenebrescence. When he returned home and tested the initial parcel with a UV lamp, Mr. Obodda was pleased to find that a few pieces showed tenebrescent behavior. He also noted a subtle but distinctive feature that could be used to differentiate the tenebrescent stones from the other material in the parcel in the absence of a UV lamp: They showed a schiller effect when viewed with a strong pinpoint light source in certain orientations.

Hackmanite, a sulfur-rich variety of sodalite, was first discovered in Greenland in the early 1800s. A mineralogical curiosity, it can be made to change repeatedly from light yellow to pink when alternately exposed to sunlight and UV radiation (see, e.g., Summer 1989 Gem News, pp. 112–113). The coloration of this Afghan material was much different, however, in that it changed from colorless to blue on exposure to UV radiation (figure 14).

Figure 14. Remarkable tenebrescent behavior was exhibited by these scapolites (0.91–5.17 ct) from Afghanistan. The stones turned blue when exposed to short-wave UV radiation for approximately one minute, and faded to colorless within seconds when brought into light. Courtesy of H. Obodda; photos by C. D. Mengason.

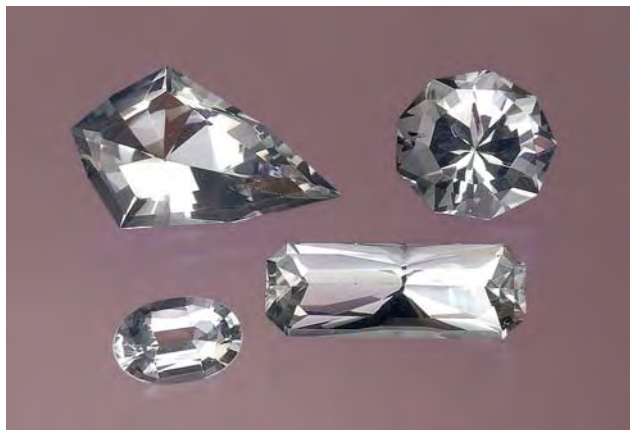
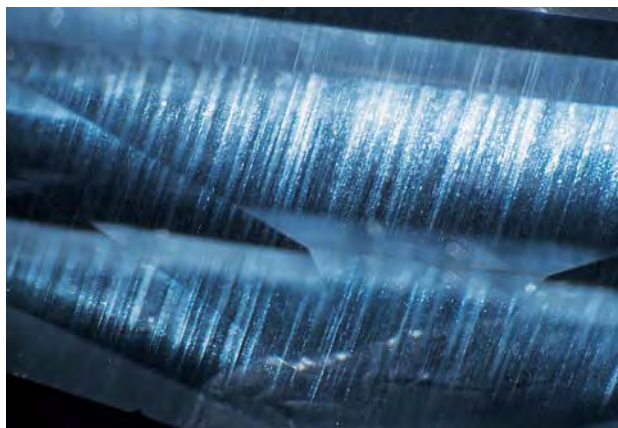




Figure 15. A dense network of parallel stringers was present in all of the tenebrescent scapolites. Photomicrograph by S. F. McClure; magnified 18x.

Mr. Obodda loaned four rough pieces (13.37–55.54 ct) and 14 faceted examples (0.17–5.17 ct) of the tenebrescent material to GIA for examination. He also donated some rough fragments to the GIA Collection. Gemological testing of four of the cut stones (0.91–5.17 ct) revealed consistent properties: R.I.'s—1.536 and 1.541, S.G.—2.58, and yellow-orange fluorescence to UV radiation (strong to long-wave and weak to short-wave). Hackmanite is optically isotropic with an R.I. of 1.483, whereas the properties of the four samples are consistent with those of scapolite (this identity was confirmed by Raman spectroscopy). When viewed with a gemological microscope, all four stones exhibited dense parallel stringers throughout (figure 15), and some contained planar clouds or “fingerprint” inclusions. The schiller effect noted by Mr. Obodda is caused by reflections from these features when

Figure 16. When viewed in certain orientations with a strong pinpoint light source, the scapolites exhibited a schiller effect that is caused by reflections from the network of parallel stringers. Photomicrograph by S. F. McClure; magnified 18x.



viewed with a strong pinpoint light source (figure 16).

When the samples were exposed to short-wave UV radiation, with the 4-watt lamp positioned nearby for approximately one minute, they changed from colorless to deep blue. The larger stones showed this effect more dramatically. Shorter exposure times also produced the blue color, but it took at least a full minute to get a saturated blue. Long-wave UV radiation also produced this color modification, but the achieved color was not as saturated. The color was stable as long as the stones were kept in a dark or dimly lit room, but they began to fade as soon as they were exposed to light (much faster in incandescent light source than in fluorescent light). In fact, an intense incandescent light source caused their color to fade completely in a few seconds. The color modification was repeated on one stone at least five times, and each time the results were the same. A brief video showing the reversible color change is available online in the *G&G* Data Depository at [www.gia.edu/gemsandgemology](http://www.gia.edu/gemsandgemology). Quantitative chemical analyses were obtained by one of us (GRR) using an electron microprobe on a polished fragment of the scapolite. The average formula derived from three analyzed points was  $\text{Na}_4\text{Al}_3\text{Si}_9\text{O}_{24}\text{Cl}_{0.9}\text{S}_{0.09}$ ; traces of carbonate may also be present but could not be analyzed by this instrument. The formula shows that the scapolite species is marialite, with a minor sulfide component. Sulfide photochemistry is what produces the blue color of lapis lazuli and red coloration in hackmanite and tugtupite.

Mr. Obodda also loaned one rough sample that was representative of the non-tenebrescent material in the parcels he purchased in Pakistan. Preliminary Raman analysis was indicative of quartz. In addition, Mr. Obodda has faceted colorless sodalite that was reported to be from the same mining area in Badakhshan. Some purple sodalite from Badakhshan also shows tenebrescence, changing from “pale lilac/magenta in artificial light to a deep purple/magenta in sunlight” (T. Moore, “What’s New in Minerals,” *Mineralogical Record*, Vol. 33, No. 1, 2002, pp. 97–98). It should also be mentioned that purple scapolite has been produced recently from the same area of Badakhshan, but it does not exhibit tenebrescence.

During his August 2005 buying trip to Pakistan, Mr. Obodda could not find any more of the colorless “hackmanite” in the marketplace. So far, he estimates that he has cut approximately 20 stones weighing less than 1 ct, a dozen weighing near 1 ct, and 10 stones in the 5 ct range; the largest stone weighed 6.7 ct.

To the best of our knowledge, tenebrescence has not been reported previously in scapolite. In addition to hackmanite, only a few other gems show this feature, such as spodumene (E. W. Claffy, “Composition, tenebrescence, and luminescence of spodumene minerals,” *American Mineralogist*, Vol. 38, 1953, pp. 919–931) and tugtupite (A. Jensen and O.V. Petersen, “Tugtupite: A gemstone from Greenland,” Summer 1982 *Gems & Gemology*, pp. 90–94). Even some pink diamonds will





Figure 17. This quartz cabochon (19 × 13 mm) from Paraíba State, Brazil, contains color-zoned clusters of radiating fibers that were identified as gilalite. Photo by B. Rondeau.

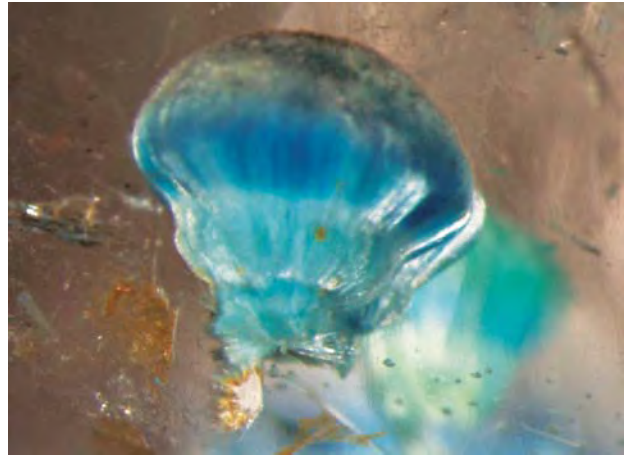


Figure 18. When viewed in certain directions, the gilalite inclusions resemble floating jellyfish medusas (here, 1.4 mm wide). Photomicrograph by B. Rondeau; magnified 16×.

change color temporarily under some conditions (see, e.g., J. Van Royan, "UV-induced colour change in pink diamonds," *Antwerp Facets*, March 1995, pp. 21–24).

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## INCLUSIONS IN GEMS

**"Medusa quartz" with gilalite inclusions.** Gem-quality quartz crystals containing interesting blue-to-green inclusions were discovered in Paraíba State, Brazil, in August 2004. Since then, about 10 kg have been extracted by local miners.

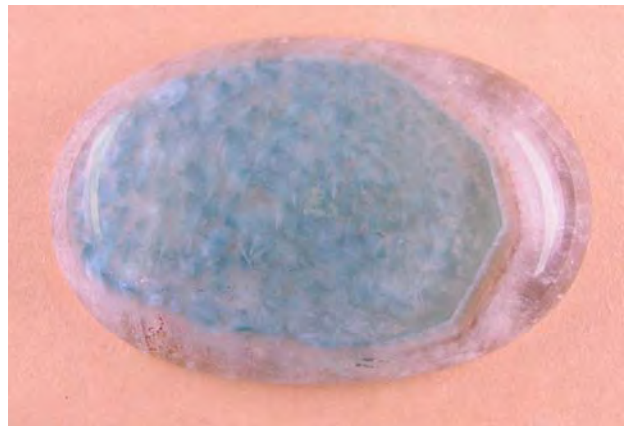
Several samples of this quartz were studied by these contributors, including some well-formed crystals, broken fragments, and cabochons. The quartz crystals were up to 10 cm long and exhibited striking color zoning: a few crystallographically oriented layers of light purple amethyst in otherwise colorless rock crystal, as well as distinct layers of eye-visible blue-to-green inclusions. Some of these blue-to-green inclusions occurred in the colorless cores of the crystals (figure 17); they were less than a millimeter in longest dimension, with shapes reminiscent of jellyfish (figure 18). All of these inclusions were located on the same growth plane, and each consisted of a cluster of very thin radiating fibers. The jellyfish-like inclusions were often color zoned, varying from light green to a vivid greenish blue, with some layers being nearly white (again, see figure 17). The overall appearance, similar to a floating colony of jellyfish, suggests the name *medusa quartz*, after the typical bell-shaped appearance of

the free-floating (medusa) stage of this sea creature. Several centimeter-size cabochons have been cut from this material.

Also present in some of the quartz crystals was a near-surface phantom layer containing tiny blue-to-green acicular crystals. About a dozen flat cabochons, 1 to 6 cm long, have been cut from these layers (see, e.g., figure 19).

The identification of the jellyfish-like inclusions was performed at the National Museum of Natural History in Paris. Their crystal structure was determined using an Inel CPS 120 X-ray powder diffractometer with a curved detector, combined with a Gandolfi single-crystal camera and copper K $\alpha$ 1 emission. Both the green and blue areas had the

Figure 19. This quartz cabochon (60 × 35 mm) from Paraíba State, Brazil, contains a layer of acicular crystals that have a chemical composition consistent with gilalite. Since X-ray diffraction could not be performed on these inclusions, additional possibilities include the copper silicates *apachite*, *planchéite*, and *shattuckite*. Photo by B. Rondeau.





same diffractogram. The most accurate match (according to the InfoBank-MDAT database) was giralite, a hydrated copper silicate ( $\text{Cu}_3\text{Si}_6\text{O}_{17} \cdot 7\text{H}_2\text{O}$ ). The tiny acicular inclusions were too dispersed in the quartz matrix to be analyzed by X-ray diffraction. Chemical analysis was performed using a Jeol JSM 840A scanning electron microscope (SEM) equipped with an Oxford Link energy-dispersive detector. Both the acicular and jellyfish-like inclusions contained Si and Cu as the only major elements (water cannot be detected with this technique), along with traces of K and Mg. The composition was the same in the blue and green areas of the medusa inclusions. The major-element composition is also consistent with giralite.

This is the first reported occurrence of giralite in quartz of gemological interest. It is quite different in form and nature from other blue inclusions in quartz, such as papagoite or lazulite (see, e.g., J. Hyrsl and G. Niedermayr, *Magic World: Inclusions in Quartz*, Rainer Bode, Haltern, Germany, 2003).

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## SYNTHETICS AND SIMULANTS

**Fake aquamarine crystals from Mogok.** During a May 2005 buying trip to Mogok, Myanmar, gem and mineral dealer Bill Larson (Pala International, Fallbrook, California) saw several imitation aquamarine crystals. They were cleverly fabricated from a transparent light blue material that had been shaped into single hexagonal prisms and then etched or rounded to have the appearance of a naturally resorbed crystal of beryl (e.g., figure 20). A natural appearance was further suggested by the presence of dirt-filled “cracks,”

*Figure 20. This glass imitation of an aquamarine “crystal” (7 cm long) was purchased in Mogok, Myanmar, in May 2005. GIA Collection no. 32382; photo by C. D. Mengason.*



which actually penetrated only a small distance into the pieces. Mr. Larson first recognized them as fakes by noting that the overall shape (with a pyramidal “termination” on one end a flat surface on the other end) resembled the typical morphology of quartz, rather than the aquamarine crystals that are known from the Mogok area. In addition, their overall look and “feel” suggested that they were made of glass. The FTIR spectrum of a specimen that Mr. Larson donated to GIA confirmed that it was glass.

BML

**More faked inclusions in Brazilian quartz.** In the Fall 2004 GNI section (pp. 266–267), this contributor described finger-like inclusions in Brazilian rock crystal that were reportedly manufactured in Teófilo Otoni in 2004. During a visit to the 2005 Feira Internacional de Pedras Preciosas show, held in Teófilo Otoni in August, several local dealers had two new types of quartz with internal features that were reportedly created by the same person responsible for the finger-like inclusions. According to vendors, this new material sells very well, and in most cases the buyers are not aware of its artificial origin.

This contributor viewed at least 100 samples of this material, all of which were cut as cabochons in various shapes that ranged from 3 to 7 cm in longest dimension (see, e.g., figure 21). In the quartz containing finger-like inclusions (see Fall 2004 entry), the “artist” apparently drilled holes in the bottom of each cabochon that were then filled with dye (green, brown, pink, and yellow) and covered with a brown glue impregnated with mineral powder. In the new fakes seen in August 2005, several trenches were made in the bases of the cabochons with a cutting wheel. The bases were then dyed green and brown and covered with a mixture of glue and mineral powder. When viewed face-up, the colored areas protruding into the quartz mimicked the appearance of natural inclusions. In addition, some of these cabochons contained dozens of silvery-looking oval fractures, similar to “spangles” in heated amber. These fractures were probably created by thermal shock.

The best clue for recognizing these new fakes, other than their unnatural appearance, is the soft brown glue on the bottom, which can easily be indented with a needle or knife. In addition, the dye used in some of the fakes shows yellow-green luminescence to UV radiation (much stronger with long-wave UV), but the cement is inert. Note that many of these cabochons also contain natural inclusions such as chlorite, mica, or quartz crystals, which can help deceive inexperienced buyers.

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## TREATMENTS

**Natural pearl with “orient-like” coating.** Recently, the SSEF Swiss Gemmological Institute received for testing a parcel of 13 loose button-shaped pearls weighing about

6 ct each. They showed moderate to good luster and orient, and ranged from white to light "cream." X-radiographs revealed that all were natural pearls, showing characteristic structures such as concentric circles, fine fissures, and darker central zones. Using X-ray luminescence (see H. A. Hänni et al., "X-ray luminescence, a valuable test in pearl identification," *Journal of Gemmology*, Vol. 29, No. 5/6, 2005, pp. 316–324), elevated Mn contents were noted in three of the samples, indicating that they were freshwater pearls, while the remainder were of saltwater origin.

Careful examination of one of the saltwater pearls (figure 22, left) revealed a somewhat patchy appearance and an unusual sticky surface. With magnification, a shiny coating was evident. The coating was transparent (with tiny trapped air bubbles) and contained minute reflective particles. When examined with a fiber-optic light, the pearl displayed a "dotted" texture similar to that seen in imitations. The coating was partially chipped off in spots (figure 23), which explained the patchy color distribution. Although not visible in figure 23, the surface of these exposed areas showed distinct polish marks.

When exposed to long-wave UV radiation, the pearl fluoresced dull yellow—except in areas where the coating was chipped off, in which the pearl surface fluoresced strong white. The reaction to short-wave UV was similar but less distinct.

Chemical analysis by EDXRF spectroscopy revealed a low concentration of Bi and traces of Sr. Bi has not been detected so far in any untreated pearl. Raman analyses of the coating with a 514 nm Ar laser were compared with spectra from the underlying pearl surface. The spectrum of the coating showed a distinct peak at  $1602\text{ cm}^{-1}$ , in addition to the characteristic Raman peaks for aragonite. The  $1602\text{ cm}^{-1}$  peak is indicative of an artificial resin.

Based on these observations, this contributor suspects

Figure 22. The 6.18 ct natural pearl on the left (shown with an untreated natural pearl on the right) proved to be coated with a resin mixed with essence d'orient. Photo by H. A. Hänni, © SSEF.



Figure 21. These rock crystal cabochons (approximately 5 cm long) from Brazil contain fake inclusions that were apparently created in a three-step process. In addition, the cabochon in the center contains reflective oval fractures that were likely induced by thermal shock. The cabochon on the right shows the base, which is covered with a mixture of glue and mineral powder. Photo by J. Hyrsl.

that this pearl had been heavily polished, which would have removed most of its original luster and orient. The pearl was apparently coated with an artificial resin mixed with some *essence d'orient*, such as is used for imitation pearls, to restore its appearance. Judging from the rather scratched and chipped surface, it seems likely that this treatment was applied many years ago.

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Figure 23. With magnification, the coating on the pearl showed several round chipped areas. Note that the coating extends partially into the drill hole. Photomicrograph by H. A. Hänni, © SSEF; magnified 20×.

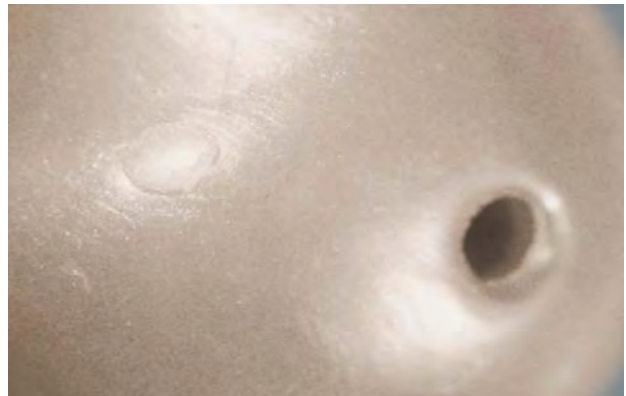


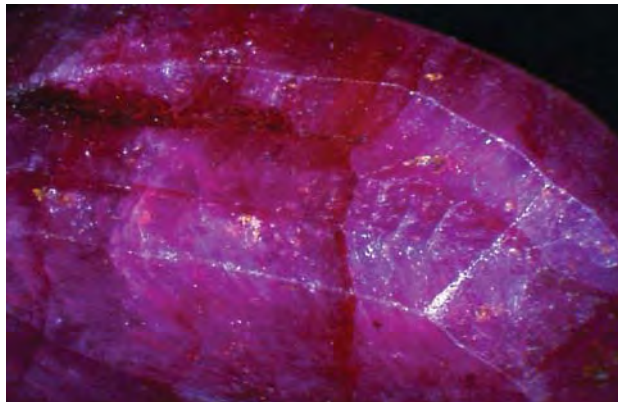


Figure 24. These two stones (9.61 and 11.40 ct) proved to be fibrolite (sillimanite) that had been dyed and impregnated to imitate ruby. Photo by S. Singbamroong, © Dubai Gemstone Laboratory.

**Fibrolite (sillimanite) dyed and impregnated to imitate ruby.** The Dubai Gemstone Laboratory received two translucent to partially transparent red oval mixed cuts for identification in mid-April 2005. At first, the 9.61 and 11.40 ct stones (figure 24) resembled low-quality rubies. When examined more closely, however, they showed an aggregate structure and uneven coloration that were visible even without magnification.

Standard gemological testing established the following properties: R.I.—1.659–1.679; birefringence—0.020; optic sign—biaxial positive; S.G. (determined hydrostatically)—3.22; Chelsea filter reaction—pink; absorption spectrum with desk-model spectroscope—600 nm cut-off; UV fluorescence—moderate red to long-wave with yellow emission along the fractures, and inert to short-wave, also with yellow emission along the fractures. These properties were consistent with fibrolite (sillimanite), but not corundum.

Figure 25. In reflected light, red dye concentrations can be seen within the fibrous structure of the sillimanite, as well as in surface-reaching fractures. The tiny yellow grains were identified as rutile by Raman analysis. Photomicrograph by S. Singbamroong, © Dubai Gemstone Laboratory; magnified 10x.



The yellow fluorescence indicated the presence of a foreign substance in the fractures, and microscopic examination revealed red dye concentrations in both stones, within their fibrous structure as well as in surface-reaching fractures (figure 25). Isolated grains and clusters of tiny “golden” yellow inclusions also were seen.

Further testing was used to verify the identification as fibrolite. Although Raman analysis failed to produce usable results because of interference from the red fluorescence, it identified the yellow surface-reaching inclusions as rutile. EDXRF chemical analysis showed the expected Al and Si as main components, along with traces of Fe and Ti. Zr also was detected, probably from the dye. In addition, V and Cr were slightly above the detection limit of the instrument. FTIR spectroscopy was performed in transmission and reflectance modes using a beam condenser and a diffuse reflectance (DRIFT) collector accessory, and the results were compared to reference spectra of cat’s-eye sillimanite. The reflectance spectra confirmed the identity of these stones as sillimanite, while the transmission spectra indicated the presence of a polymer.

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## CONFERENCE REPORTS

**Applied Diamond Conference 2005.** The 8th International Conference on Applications of Diamond and Related Materials was held May 15–19 at Argonne National Laboratory, Argonne, Illinois. The conference included several presentations of interest to gemologists. Abstracts are available by downloading the Program Book from the conference Web site, <http://nano.anl.gov/adc2005>.

**Dr. Mark Newton** of the University of Warwick, U.K., and coauthors discussed two new hydrogen defects (vacancy-hydrogen and vacancy-nitrogen-hydrogen complexes) in CVD synthetic diamonds, their spectroscopic signatures, and their behavior during HPHT and low-temperature annealing. **Dr. Peter Doering** of Apollo Diamond, Boston, Massachusetts, reviewed the effect of HPHT treatment on defects and optical properties of single-crystal CVD synthetic diamond. In the question-and-answer session, he stated that Apollo plans to release their CVD synthetic diamonds into the gem market around the middle of 2006. **Dr. Chih-Shue Yan** and coauthors of the Geophysical Laboratory, Carnegie Institution, Washington, DC, described recent progress in growing large single-crystal CVD synthetic diamonds. The Carnegie group can now grow CVD synthetic diamonds (figure 26) at a rate of 100 microns/hour (compared to a traditional growth rate of 1 micron/hour) by using a focused plasma beam. The maximum thickness of the CVD layer achieved so far is 12 mm, and plates weighing up to 10 ct have been grown. Some of their CVD synthetic diamonds also have been annealed by HPHT methods.





Figure 26. This 0.2 ct near-colorless CVD synthetic diamond was cut from a 1 ct block produced at a high growth rate using a focused plasma beam. Courtesy of the Carnegie Institution, Washington, DC.

**Dr. Wuyi Wang** and coauthors from the GIA Laboratory, New York, discussed the common spectroscopic features and defects in three types of treated diamonds: (1) irradiated with or without annealing; (2) HPHT annealed; and (3) HPHT annealed, followed by irradiation and annealing. Various identification criteria were discussed, such as blue/yellow zones concentrated on the culet (indicating laboratory irradiation), green/brown radiation stains on "naturals" (indicating natural irradiation), and spectroscopic features (i.e., a height ratio of  $>2$  for photoluminescence peaks at 637/575 nm is an indication of HPHT annealing, and the existence of both 595 and 666 nm absorptions in the visible-range spectra is a strong indication of laboratory irradiation). **Dr. Filip De Weerd** of HRD, Antwerp, Belgium, and **Dr. Hisao Kanda**, of the National Institute of Research on Inorganic Materials, Tsukuba, Japan, described the color changes produced in type IaA and IaB diamonds by HPHT annealing. They used a cathodoluminescence (CL) unit attached to a scanning electron microscope for simultaneous imaging and spectroscopic analysis of their samples before and after HPHT annealing. A CL line at 490.7 nm was clearly associated with the untreated diamonds.

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**Goldschmidt05.** The 15th Annual Goldschmidt Conference was held May 20–25 at the University of Idaho, Moscow. This is the premier annual geochemistry conference, and was attended by more than 1,400 delegates from around the world. Two sessions, "Geochemistry of Gem Deposits" and "Recent Advances in Microbeam Cathodoluminescence," plus a few individual talks and posters, were of interest to gemologists. Abstracts of all presenta-

tions are available online at [www.the-conference.com/2005/gold2005/abstract\\_volume.php](http://www.the-conference.com/2005/gold2005/abstract_volume.php).

**Dr. Emmanuel Fritsch** of the University of Nantes, France, and colleagues presented a new geochemical method to separate basaltic from metamorphic blue sapphires: a plot of Fe content vs. Ga/Mg ratio. **Emilie Gaillou** of the University of Nantes and coauthors analyzed opals from seven countries using ICP-MS. Mexican opals showed Ce depletion, while Ethiopian opals had Ce enrichment, relative to the chondrite standard used by geochemists. In addition, geochemical profiling (i.e., plotting Ba vs. Ca) showed promise for identifying the geographic/geologic origin of opal: Those from Mexico, Honduras, and Ethiopia fell into a field for volcanic origin; those from Brazil and Australia occupied a field corresponding to a sedimentary origin.

**Dr. Lee Groat** and **Heather Neufeld** of the University of British Columbia, Vancouver, reviewed the geology of four emerald deposits in Canada: (1) Taylor 2, near Dryden, Ontario; (2) Red Mountain, near Stewart, British Columbia; (3) Tsa Da Glisza, southern Yukon Territory; and (4) Lened in the western Northwest Territories. **Andrea Cade** and coauthors, also of the University of British Columbia, studied sapphires from a calc-silicate lens within the Lake Harbour Marble unit at Kimmirut, Baffin Island, Canada, and indicated that they could have formed through the alteration of a protolith assemblage of diopside, phlogopite, calcite, anorthite, and albite. **Anthony LeCheminant** of Petrogen Consultants, Manotick, Ontario, and coauthors proposed a different origin for the sapphires from Kimmirut. Using field observations, oxygen isotope data, and zircon ages, they speculated that the sapphires formed through the interaction of a desilicated syenitic magma with the Lake Harbour Marble, accompanied by further retrograde reactions and subsequent infiltration of CO<sub>2</sub>-rich liquids. **David Turner** of the University of British Columbia and coauthors studied the mineralogy and geochemistry of dark blue gem-quality aquamarine from the Pelly Mountains, southern Yukon Territory. They found that the beryl-bearing quartz veins were emplaced in an extensional environment about 172 million years ago, and were unrelated to their Late Paleozoic host syenite intrusion.

**Dr. George Rossman** of the California Institute of Technology, Pasadena, and coauthors described some waterworn crystals of the rare gem painite that were recovered from a new locality for the mineral, only the second ever reported, at Namya (Nanyaseik), Kachin State, Myanmar. **Dr. Mickey Gunter** of the University of Idaho and colleagues concluded that asterism in Idaho star garnets is caused by oriented rutile inclusions or tubular voids in the almandine. **Catherine McManus** of New Mexico State University and coauthors did a preliminary study of the trace-element content of gem beryl using LIBS (laser-induced breakdown spectroscopy).

A breakthrough in microbeam cathodoluminescence

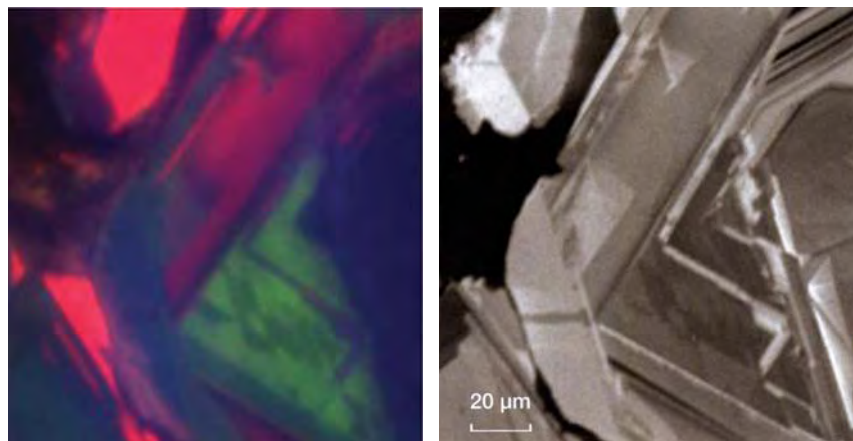


Figure 27. These CL images of jadeite from Guatemala were captured by a digital camera on a tabletop luminoscope (left) and by a Gatan MonoCL high-sensitivity photomultiplier tube mounted on a scanning electron microscope (right). On the left, the green CL area correlates to greater contents of Ca, Mg, Fe<sup>2+</sup>, and Mn (and, in some cases, Cr) than in the red or blue CL areas. The image on the right shows the total CL intensity of the sample. Images collected by Tim Rose, Smithsonian Institution.

(CL) has been facilitated by attaching a newly developed digital CL unit to a scanning electron microscope, which allows researchers to obtain optical spectra (hyperspectral analysis) and a chemical analysis simultaneously. In Guatemalan jadeite, **Dr. Sorena Sorensen** and coauthors from the Smithsonian Institution, Washington, DC, documented patterns of red (675 nm), blue (475 nm), and green (550 nm) luminescence that corresponded to micron-scale compositional variations that formed during growth (figure 27). **Dr. George Harlow** of the American Museum of Natural History, New York, and colleagues used this technique to differentiate between the two major geologic settings for Guatemalan jadeite. Samples from south of the Motagua Fault Zone (MFZ) showed CL peaks at 270 and 480 nm, while those from north of the MFZ had a dominant CL peak at 700 nm and two smaller peaks at 500 and 480 nm. In addition, they documented extremely fine, bright bands (less than 10 µm thick) in rubies from Myanmar, indicating that their growth was influenced by pulses of fluid in the marble host.

In another presentation, **Dr. Harlow** also characterized four types of Guatemalan jadeite: (1) material from north of the MFZ is a jadeite-omphacite-zoisite assemblage that formed at 300–400°C and 6–10 kbar; (2) San José material consists of a jadeite-omphacite-lawsonite-quartz assemblage, formed at 300–400°C and 12–20 kbar; (3) La Ceiba material contains jadeite-omphacite-diopside-quartz, and formed at 300–400°C and 10–14 kbar; and (4) La Ensenada material is jadeite-omphacite-pumpellyite, suggesting formation conditions of 200–300°C and 6–9 kbar. **Dr. Emilie Thomassot** of the Institut de Physique du Globe de Paris and coauthors studied the stable isotope composition of sulfide inclusions in diamond, and found that the sulfides had different origins than their host diamonds. They concluded that the sulfide-included diamonds were of metasomatic origin. **Lutz Nasdala** of Johannes Gutenberg Universität, Mainz, Germany, and colleagues showed the results of mapping strain around an inclusion in diamond using a laser Raman microspectrometer. Such analysis can be useful in estimating the P-T conditions of diamond formation.

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GIA Laboratory, Carlsbad

## MISCELLANEOUS

**Historic U.S. sapphire and benitoite mines close.** *G&G* author Keith Mychaluk (Calgary, Alberta, Canada) informed this contributor that the Vortex sapphire mine at Yogo Gulch, Montana, closed in late November 2004. According to Peter Ecker of Yogo Creek Mining (Hobson, Montana), the sapphire ore had become much less friable at depth (over 120 m), which made both the extraction and processing of the ore less economic. In addition, the thickness of the lateral dike formation being mined had pinched considerably. Most of the surface workings have been reclaimed, and the remaining sapphire inventory has been sold to Adair Jewelers in Missoula, Montana.

Also, this contributor has been informed by Bryan Lees (The Collector's Edge, Golden, Colorado) that his company permanently closed and reclaimed the Benitoite Gem mine (San Benito County, California) in June 2005. He indicated that both the lode and eluvial sources were commercially exhausted. A caretaker will remain on the property indefinitely to oversee the revegetation and dissuade trespassers. Mr. Lees indicated that he will now focus efforts on marketing the stockpile of benitoite gem rough that his firm has accumulated over the past five years of mining the property.

BML

## ANNOUNCEMENTS

### Conferences

**Mineralien Hamburg.** The International Show for Minerals, Fossils, Precious Stones and Jewellery will take place in Hamburg, Germany, on November 9–11, 2005. Special exhibitions will feature gems, jewelry, and mineral specimens owned by Russia's tsars, as well as Native American turquoise. Visit [www.hamburg-messe.de/mineralien](http://www.hamburg-messe.de/mineralien).

**Visit *Gems & Gemology* in Tucson.** Meet the editors and take advantage of special offers on subscriptions and back issues at the *G&G* booth in the publicly accessible Galleria section (middle floor) of the Tucson Convention Center during the AGTA show, February 1–6, 2006.

GIA Education's traveling Extension classes will offer

hands-on training in Tucson with "Diamond Grading" (January 30–February 3). To enroll, call 800-421-7250, ext. 4001. Outside the U.S. and Canada, call 760-603-4001.

The GIA Alumni Association will host a Dance Party in Tucson on February 3, featuring a silent auction, an industry awards presentation, and a live auction. To reserve tickets, call 760-603-4204 or e-mail [events@gia.edu](mailto:events@gia.edu).

**CGA Gemmology Conference 2005.** The Canadian Gemmological Association is holding its annual conference at the Ontario Club in Toronto on November 4–6. This year's conference, "Tricks and Treatments," will explore historical gemstone deceptions and the latest developments in treatments, enhancements, and detection. Visit [www.canadiangemmological.com](http://www.canadiangemmological.com) or call 416-785-0962.

### Exhibits

**Cameos at the Met.** "Cameo Appearances," a display of more than 160 examples of the art of gem carving from Greco-Roman antiquity to the 19th century, will be on display until January 29, 2006, at the Metropolitan Museum of Art in New York City. A variety of educational programs will be offered in conjunction with the exhibition. Also on display at the Met (through February 12, 2006) is "The Bishop Jades," a selection of fine Chinese and Mughal Indian jades from the collection of Heber R. Bishop that was donated to the museum in 1902. Visit [www.metmuseum.org](http://www.metmuseum.org) or call 212-535-7710.

**Diamonds in London.** "Diamonds," an exhibit of some of

the world's most important diamonds, is at the Natural History Museum in London through February 26, 2006. On display are the De Beers Millennium Star, the Steinmetz Pink, the Ocean Dream, and the Moussaieff Red (see J. M. King and J. E. Shigley, "An important exhibition of seven rare gem diamonds," Summer 2003 *Gems & Gemology*, pp. 136–143), in addition to a 616 ct rough diamond. Visit [www.nhm.ac.uk/diamonds](http://www.nhm.ac.uk/diamonds).

**Pearls at the Tokyo National Science Museum.** "Pearls: A Natural History," a traveling exhibition tracing the natural and cultural history of pearls that was organized by the American Museum of Natural History (New York) in collaboration with the Field Museum (Chicago), will be on display at the National Science Museum, Tokyo, October 8, 2005 to January 22, 2006. The many exhibits include pearl formation and culturing, as well as historical pearl jewelry that once belonged to Great Britain's Queen Victoria and Marie Antoinette of France. Call 81-03-3822-0111.

### ERRATUM

The Winter 2004 Gem News International entry titled "A notable triplite from Pakistan" reported that the stone originated from the Shigar Valley in northern Pakistan, but information recently obtained from a reliable local miner indicates that the triplite came from the Namlook mine, which is above the village of Dassu in the Braldu Valley, also in northern Pakistan. We thank Dudley Blauwet for bringing this update to our attention.

## IN MEMORIAM: CORNELIUS S. HURLBUT, JR. (1906–2005)

*Gems & Gemology* mourns the loss of longtime contributor and Editorial Review Board member Cornelius S. Hurlbut, Jr. Dr. Hurlbut passed away September 1 at the age of 99.

Connie Hurlbut was born June 30, 1906, in Springfield, Massachusetts. After receiving his undergraduate degree at Antioch College in Ohio, he obtained a master's degree and a doctorate in petrography from Harvard University. Dr. Hurlbut joined the Harvard faculty in 1934 as a petrography instructor and became Professor of Mineralogy six years later. He went on to chair the university's Mineralogy Department from 1949 to 1960 before retiring in 1972 and becoming Professor Emeritus.

In addition to his distinguished teaching career, Dr. Hurlbut was a widely published author with several important books and more than 100 scientific papers to his credit. Between 1941 and 1993, he edited the 15th through 21st editions of *Dana's Manual of Mineralogy*, a classic reference in the field. He was the author of *Minerals and Man* (1968), as well as coauthor of *The Changing Science of Mineralogy* (1964) and editor of *The Planet We Live On: An Illustrated Encyclopedia of the Earth Sciences* (1978).

In retirement, Dr. Hurlbut turned more to gemology,

an affiliation that began in the 1940s when he joined GIA's Educational Advisory Board. He taught a gemology course at Boston University in the early 1970s and coauthored (with George Switzer) the first edition of *Gemology* in 1979 (the second edition, co-authored with Robert Kammerling, was published in 1991). Dr. Hurlbut contributed his intellect and expertise to *Gems & Gemology* as a member of the journal's Editorial Review Board from 1981 until his passing. He also wrote or coauthored several articles for the journal, including "A Simple Procedure to Separate Natural from Synthetic Amethyst on the Basis of Twinning" (Fall 1986, pp. 130–139), which received first place in that year's Most Valuable Article competition.

Among his many distinctions, Dr. Hurlbut was a 1955 Guggenheim Fellow, a former president of the Mineralogical Society of America, and a recipient of the 1994 Carnegie Mineralogical Award for his contributions to the field. Preceded in death by his wife, Margaret, Dr. Hurlbut is survived by three children, six grandchildren, and six great-grandchildren. Always the gentleman, in criticisms and compliments alike, his sharp wit, brilliant mind, and kind manner will be missed.



# GEMS & GEMOLOGY®

## CHALLENGE WINNERS

This year, 236 dedicated readers participated in the 2005 GEMS & GEMOLOGY Challenge. Entries arrived from all corners of the world, as readers tested their knowledge on the questions listed in the Spring 2005 issue. Those who earned a score of 75% or better received a GIA Continuing Education Certificate recognizing their achievement. The participants who scored a perfect 100% are listed below. Congratulations!

**AUSTRALIA** *Grange, South Australia*: Barbara Wodecki • **BELGIUM** *Diegem*: Guy Lalous. *Diksmuide*: Honoré Loeters. *Hemiksem*: Daniel De Maeght. *Koksijde*: Christine Loeters. *Overijse*: Margrethe Gram-Jensen. *Ruiselede*: Lucette Nols. *Tervuren*: Vibeke Thur • **BRAZIL** *Rio de Janeiro*: Luiz Angelo • **CANADA** *Bobcaygeon, Ontario*: David Lindsay • **ENGLAND** *Hereford*: Michael Langford. *London*: Douglas Kennedy • **FRANCE** *Draveil*: Claire Carpentier • **INDONESIA** *Jakarta*: Warli Latumena • **ITALY** *Ferrara*: Sonia Franzolin. *Padova*: Marco Maso. *Porto Azzurro*: Diego Trainini • **THE NETHERLANDS** *Rotterdam*: E. Van Velzen • **POLAND** *Lublin*: Marek A. Prus • **SPAIN** *Valencia*: Monika Bergel-Becker. *Rocafort*: Elvira Orts Rodriguez. *Salou*: Santiago Escolá • **SWEDEN** *Jarfalla*: Thomas Larsson • **SWITZERLAND** *Lausanne*: Thierry Christe • **THAILAND** *Bangkok*: Surachart Panjathammawit, Potjana Sawangjitr • **UNITED STATES** **Arizona** *Chandler*: LaVerne Larson. *Cottonwood*: Glenn Shaffer. *Tucson*: Molly Knox. *Yuma*: Crystal Young. **Arkansas** *Greenbrier*: Beverly Brannan. **California** *Burlingame*: Sandra MacKenzie-Graham. *Carlsbad*: Abba Steinfeld, Jim Viall, Lynn Viall, Philip York, Marisa Zachovay. *Culver City*: Veronica Clark-Hudson, Judith Shechter-Lankford. *Fremont*: Ying Ying Chow. *Fullerton*: David Le Rose. *Marina Del Rey*: Veronika Riedel. *Oceanside*: Kevin Nagle. *Orange*: Alex Tourubaroff. *Pacifica*: Diana Gamez. *Rancho Cucamonga*: Sandy MacLeane. *Redwood City*: Starla Turner. **Connecticut** *Vernon*: Joe Thon Negs. **Florida** *Clearwater*: Timothy Schuler. *Deland*: Sue Angevine Guess. *Sun City*: Jeanne Naish. **Hawaii** *Honolulu*: Brenda Reichel. *Makawao*: Alison Fahland. **Illinois** *Normal*: William Lyddon. **Indiana** *Carmel*: Mark Ferreira. *Fishers*: Laura Haas. *Greenfield*: Rachelle Kihlstrum. *Indianapolis*: Wendy Wright Feng. **Maryland** *Burtonsville*: Jody Tebay. *Gaithersburg*: Marvin Wambua. **Massachusetts** *Uxbridge*: Bernard Stachura. **Missouri** *Perry*: Bruce Elmer. **New Jersey** *Clifton*: Jason Darley. **New York** *Hawthorn*: Lorraine Bennett. *New York*: Carolyn van der Bogert, HyeJin Jang-Green, Wendi Mayerson, Anna Schumate. **North Carolina** *Candler*: Christian Richart. **Ohio** *Dayton*: Michael Williams. *North Ridgeville*: John Schwab. *Toledo*: Mary C. Jensen. *West Jefferson*: Carolyn Loomis. **Pennsylvania** *Leesport*: Lori Perchansky. *Schuylkill Haven*: Janet Steinmetz. *Yardley*: Peter Stadelmeier. **Rhode Island** *Rumford*: Sarah A. Horst. **South Dakota** *Piedmont*: Randell Kenner. **Tennessee** *Clarksville*: Kyle Hain. *Knoxville*: Nicole Hull. **Texas** *Plano*: Kristina Oberg. **Virginia** *Hampton*: Edward Goodman. *Herndon*: Lisa Marsh-Vetter, Stephen M. Vetter. **Washington** *Ferndale*: Candice Gerard. *Millcreek*: Nicki Taranto. *Redmond*: Andrea Frabotta. **Wisconsin** *Beaver Dam*: Thomas Wendt. *Mequon*: Katie Molter • **ZIMBABWE** *Harare*: Lesley Faye Marsh.

Answers (see pp. 74–75 of the Spring 2005 issue for the questions): 1 (b), 2 (d), 3 (b), 4 (a), 5 (d), 6 (c), 7 (b), 8 (c), 9 (b), 10 (a), 11 (c), 12 (d), 13 (c), 14 (a), 15 (d), 16 (c), 17 (a), 18 (d), 19 (a), 20 (b), 21 (d), 22 (c), 23 (b), 24 (a), 25 (c)



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## EDITORS

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### Shinde Jewels

By Reema Keswani, 79 pp., illus., publ. by Assouline Publishing, New York, 2004. US\$18.95\*

This is a spare, unassuming book that clearly reflects a spare, unassuming designer. A man of humble beginnings, Ambajii V. Shinde led a modest lifestyle and sought only excellence in his art—an art that was a way of life from the time he was a young boy until his death in 2003 at the age of 85. Though he never strove for notoriety, he was sought out by Indian and British royalty as well as by Hollywood glitterati. Harry Winston had the vision to ask Shinde to join his New York firm in 1959, then to head the studio in 1966. What a marriage of passion and art this was: A.V. Shinde, the incomparable designer, and Harry Winston, the man with the cornucopia of gemstones.

A. V. Shinde was responsible for designing some of the most magnificent jewels of the 20th century, including the settings for the Star of Sierra Leone, Étoile du Désert, Taylor-Burton, Star of Independence, and Garuda diamonds. Yet he remained largely unknown outside the world of *haute couture* jewelry. He did not sign his work, only the renderings—the design was his signature. Though these pieces displayed a profusion of diamonds and gemstones, the symmetry, elegance, and stark minimalism started a revolution in design and wearability.

The 49 pages of lavish color photographs and renderings, unfettered by captions, stand in silent testimony to this quiet, elegant man. Here you mainly see the object and the wearer,

or the object and the rendering, side by side: sumptuous tiaras and gently folded gem-studded necklaces, both classical Mogul and classical Winston. Then, the four pages of thumb-nails in the back of the book give the attributions you crave: dates, styles, and the names of those fortunate to wear these beautiful jewels. When you review these descriptions, you see that the classicism that followed his work from the early 1940s and 1950s is still fresh today.

GAIL BRETT LEVINE  
National Association of  
Jewelry Appraisers  
Rego Park, New York

### The History of Beads: From 30,000 B.C. To the Present

By Lois Sherr Dubin, 364 pp., illus., publ. by Harry N. Abrams, New York, 2004. US\$29.95

Anyone who feels that the common agate or glass bead is somewhat, well, common, will be chastened after reading this unique book. As *Ornament Magazine* editor Robert K. Liu explains in his foreword, it was written primarily for bead collectors, who must often go to a wide variety of scholarly publications to ferret out information on beads. But the book also has much to offer cutters, gemologists, and jewelers—anyone interested in jewelry. The ancient (circa 3000 BC) agate eye beads pictured in the book are amazing in their shapes and polish. Weight lost through cutting a more desirable shape or size raised the value of these beads, just as it

does for cut stones today. And ancient strands of beads are often amazingly modern in their combinations of bead size, shape, and color.

Dubin is less interested in beads as jewelry, however, than she is in beads as important artifacts of human culture and history. She emphasizes how people from around the world and through all ages of human history have used beads as trade goods, talismans, tokens of wealth and status, religious objects, and (usually only secondarily) ornaments. As a result, the book is an exceptional reference and resource, yet also very readable. It abounds with human stories related to beads. The author debunks the myth that the island of Manhattan was purchased for \$24 in beads. She gives a chilling example of the secrecy that existed on the Venetian glass-making island of Murano, where at least two men were executed for violating the local prohibition against divulging glass-making secrets. She discusses the theories of explorers Richard Francis Burton and Henry Morton Stanley regarding the disappearance of literally tons of glass beads that were traded into Africa. Throughout, she talks about the beads—stone, glass, wood, bone, pearl, shell, metal—that have been worn, used, and treasured by human beings for their color, their symbolism, and their value.

*\*This book is available for purchase through the GIA Bookstore, 5345 Amada Drive, Carlsbad, CA 92008. Telephone: 800-421-8161; outside the U.S. 760-603-4200. Fax: 760-603-4266. E-mail: myorder@gia.edu*



Dubin's book discusses beads from almost every area of the world. There are separate chapters covering large categories of special types of beads: prayer beads, magic-eye beads, amber, and pearls. The volume closes with a chapter on contemporary beads. Although they may be modern in materials (such as niobium), the beads manufactured today owe much to their predecessors.

The book's images are riveting (more than two-thirds of the 356 illustrations are in color), and you can hardly turn a page without finding an exceptionally high quality illustration, map, or photograph, with many of the photos taken by Kiyoshi Togashi. The only complaint I have about the superb photographs—of single beads, strung beads, and beads being held, worn, and made—is that they cannot fulfill the desire they create, the desire to reach into the book and touch and hold these wonderful treasures.

*The History of Beads* is an excellent research reference. The bibliography is extensive, the index is complete, and the end notes are filled with information. (For example, in Dubin's section on Middle American jade, she mentions that it takes four hours to cut through an inch of jade using ancient methods. She doesn't explain those methods in the text, but a check of the end notes provides the description.) A sewn binding and heavy, high-quality paper mean that this book can be used and enjoyed for years. The eight-page pull-out chart of beads throughout history provides a wonderful overview of the human culture embodied in these tiny artifacts. A glossary and bead-shape table complete the resources.

From a deep appreciation of beads, gained through 30 years of collecting, Dubin has strung a narrative with human hopes, fears, beliefs, and desires, like beads on a common strand. Even those with no interest in beads should leave her book with a healthy respect for this "universal object" of infinite variety.

SHARON ELAINE THOMPSON  
Salem, Oregon

### **Totems to Turquoise: Native North American Jewelry Arts of the Northwest and Southwest**

*Edited by Kari Chalker, Lois S. Dubin, and Peter M. Whiteley, 224 pp., illus., publ. in association with the American Museum of Natural History by Harry N. Abrams, New York, 2004. US\$45.00\**

In 2000, a cultural exchange program brought Northwest Coastal Indian artists to Arizona and New Mexico, and Southwestern native artists to British Columbia. The program introduced talented Haida, Navajo, and Pueblo jewelers to one other and gave them an opportunity to share their cultures and arts. The exchange program eventually resulted in the recently concluded "Totems to Turquoise" exhibition at the American Museum of Natural History (AMNH) in New York. Created as a companion to the exhibit, this book focuses on 39 contemporary North American native artists, their work, and their thoughts on individual roles and responsibilities in supporting their cultures and communities.

This high-quality 9.25 × 11.25 in. book is divided into two main sections, "The Northwest Coast" and "The Southwest," and includes 150 full-color pages, two maps, and numerous historical photos. Introductory chapters discuss each region's landscape, culture, and history, followed by biographies of earlier master jewelers such as Charles Edenshaw, Bill Reid, Kenneth Begay, Preston Monongye, and Charles Loloma. Sections on contemporary artists follow those of the master craftsmen. Noted photographer Kiyoshi Togashi took the majority of the photos, including images of the artists that accompany their personal statements and examples of their art.

An intimate portrait of each artist emerges. The personal statements in each section collectively create a larger impression of the group they represent. The totality of both sections gives an even deeper understanding of

the importance jewelry and art have played in maintaining the identities and cultures of the Native North Americans from these two vastly different regions. Both groups draw from their age-old traditions, while some individuals push their art forms forward in new and exciting ways.

Native American art continues to reach a wider audience and gain a higher level of appreciation among jewelry collectors worldwide. This book honors that artwork and describes the history and craftsmanship used to create it. The historical background and related essays are written by editor/anthropological writer Kari Chalker, AMNH museum curators Lois S. Dubin and Peter M. Whiteley, Haida artist Jim Hart, and anthropologist Martine Reid. Their essays provide an excellent background on the two cultures and insight into the contemporary art coming from both areas. While no valuations of pieces are given, *Totems to Turquoise* is a wonderful reference book for collectors, students, jewelry designers, and jewelry historians.

MARY MATHEWS  
Gemological Institute of America  
Carlsbad, California

### **Exploration Criteria for Coloured Gemstone Deposits In the Yukon**

*By Lori Walton, 184 pp., illus., publ. by the Yukon Geological Survey, Whitehorse, Canada, 2004. C\$5.00 (no charge for PDF version).  
www.geology.gov.yk.ca*

Providing more than its title suggests, this book is a wonderful overview of nondiamond gemstone geology, nicely updated from its original 1996 format. The intended audience is geologists and prospectors, already scouring Canada's north for diamonds and precious and base metals, who are encouraged to keep an eye open for colored gems. The author summarizes many classic gem deposits from around the world and breaks them

down into basic components (e.g., geochemistry), which in turn could be applied to the exploration for new deposits in the Yukon or elsewhere.

Chapters are devoted to ruby/sapphire, emerald, tsavorite/tanzanite, chrysoberyl (including alexandrite), pegmatite gems (including tourmaline, topaz, and aquamarine), and gem topaz/red beryl in rhyolites, making this one of the more comprehensive guides to the geology of colored gems. There is heavy emphasis on practicality and application. Field identification of rough material is covered, as are recommended recovery tools and limitations (e.g., how to apply the tanzanite exploration tips when there is only one known economic occurrence).

The text is very readable, even for someone without a background in geology or a related discipline (although a geology dictionary would be helpful for those not familiar with specific terminology). As such, this publication is “one-stop shopping” to start learning about or review colored stone geology and exploration.

The author has provided an exceptional up-to-date reference list at the end of each chapter, for those wishing to dive into greater detail. The occasional footnote also references relevant Web sites.

The author enriches the technical portions of the text with human-interest stories or government policies associated with the gem under discussion. The discovery and subsequent flurry of mining and claim-jumping at the Hematita, Brazil, alexandrite deposit is one such example. These stories add a depth to the text that can be rare among scientific publications.

There is one unattributed statement, on page 30, that I would contest; it suggests that blue sapphires from Yogo, Montana, are heat-treated. Vortex Mining (not mentioned in the

text) has been mining and selling Yogo sapphires for over a decade and in fact does not heat-treat their stones.

Since this is a summary and not a unique research project, the text sometimes borrows heavily from other well-known sources (e.g., *Ruby and Sapphire*, by Richard Hughes), although they are properly acknowledged. Overall, however, the format is unique and refreshing, in that few texts of this scope have included lesser-known gems (e.g., tsavorite and tanzanite) with the traditional “Big Three” (ruby, sapphire, and emerald), although the latter still constitute more than half the text. On that note, this reviewer would encourage future editions of this publication to include opal (an obvious omission), peridot, Ammolite, and—in the pegmatite section—more on the spodumene gems (kunzite and hiddenite).

KEITH MYCHALUK  
Calgary, Alberta, Canada

## OTHER BOOKS RECEIVED

**The Pegmatite Mines Known as Palermo.** By Robert W. Whitmore and Robert C. Lawrence Jr., 213 pp., illus., published by *The Friends of Palermo Mines*, 2004. US\$150.00. This book, an obvious labor of love, recounts the history of the Palermo mines of North Groton, New Hampshire, along with their secrets, as an economically important producer of industrial mica, feldspar, and beryl. Also included is a beautifully illustrated (by Frederick C. Wilda) catalog of the many minerals—as of March 2004, 90 phosphates and 140 mineral species in all—that have been found since the mine was first worked in 1878. Another section focuses on gemstones fashioned from Palermo

beryl and quartz. The rich history of the Palermo mines and their significance to science, industry, and collectors have been captured well in this beautiful work, and the story continues as the mine serves today as a “living laboratory.”

MICHAEL EVANS  
Gemological Institute of America  
Carlsbad, California

**Tourmalines of Malkhan.** By V. Ye. Zagorsky, I. S. Peretyazhko, and V. Ye. Kushnaryov, 31 pp., illus., publ. by the Institute of Geochemistry, Russian Academy of Sciences (Siberian Division) and Tourmalkhan Co., Irkutsk, Russia, 2005. US\$20.00 (E-mail: victzag@igc.irk.ru). In 1980, Soviet geologists searching for radioactive elements discovered gem tourmalines in the Malkhan pegmatites of Siberia's Central Transbaikalia region. Since then, this 60-square-mile (97 km<sup>2</sup>) area has emerged as a significant source of pink-to-red, multicolored, and “watermelon” tourmaline. *Tourmalines of Malkhan* describes the occurrence of tourmaline in this region and features color photos of faceted stones and cabochons, as well as crystal specimens.

STUART OVERLIN  
Gemological Institute of America  
Carlsbad, California

**Gemstones: Quality and Value, Volume 1.** By Yasukazu Suwa, 143 pp., illus., publ. by Sekai Bunka Publishing, Tokyo (revised English edition), 2005. US\$99.95. \* Originally published in 1993, this volume examines 24 gem varieties and provides an illustrated quality scale for assessing their value. The book's clear, systematic approach is supplemented by rich color photography. This edition features several updated quality scales and photos.

SO

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## COLORED STONES AND ORGANIC MATERIALS

**Gravitationally banded (“Uruguay-type”) agates in basaltic rocks—where and when?** J. Petránek, *Bulletin of Geosciences*, Vol. 79, No. 4, 2004, pp. 195–204.

This article suggests new terminology to describe the banding of agates, in order to alleviate the confusion caused by previous descriptors that have no direct correlation to genetic implications. One ambiguous term, *Uruguay banding*, has been used to describe the straight parallel banding that often occurs in the lower portions of agate-containing vesicles from continental flood basalts. Confusion results because agates with this type of banding are called *Uruguay agates*, a term that some use to describe any agate from Uruguay.

The author suggests using *gravitational banding* to refer to all agate textures caused by the force of gravity, which in this case applies to the deposition of relatively thick bands of coagulated silicic acid. The term *adhesional banding* is suggested as a replacement for terms such as *concentric*, *common*, *normal*, and *fortification banding*; these all refer to the thin layers of silica that adhere to the vesicle walls and form concentric rings or zones.

Both types of banding commonly occur in agates formed in continental flood basalts from many locations worldwide. Several factors, including the amount and thickness of the lava flow, the temperature and humidity of the region, and the amount of CO<sub>2</sub> in the atmosphere, all contribute to the formation of the agate-filled vesicles. A suitable lava thickness will facilitate a slow cooling rate, which allows for the coalescence of numerous gas bubbles into larger vesicles and voids. Conversely, cooler atmospheric temperatures will inhibit vesicle formation. Sufficient rainfall will provide enough water for

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hydrothermal circulation within the lava flow to dissolve and transport silica for agate deposition. In combination with abundant rainfall, sufficient atmospheric CO<sub>2</sub> will facilitate the formation of carbonic acid. This aids in the chemical weathering of the basalt, releasing the silica and making it available for agate formation. Based on such requirements, the author suggests that the presence of both gravitational and adhesional banding is largely controlled by climate. EF

**The underworld of ivory.** R. T. Naylor [thomas.naylor@mcgill.ca], *Crime, Law & Social Change*, Vol. 42, No. 4–5, 2004, pp. 261–295.

This article offers a detailed history of the demand for and trade in ivory, noting that it was probably the first organic material used for human ornamentation and was perhaps the world's first globally traded commodity, pre-dating gold. Ivory from East Africa began reaching the Roman Empire as early as the 2nd century BC, India from the 7th century AD, and China shortly afterward. Although elephants also were native to parts of Asia, there they were valued as work animals, while Africans regarded their variety as a destructive pest.

There was little concern about the slaughter of African elephants until the 1970s, when hunting, poaching (in response to soaring prices for ivory), and wars in various African states decimated the herds. Although trade in ivory was banned globally in 1989, demand, principally from Asia, has fueled an underground trading network for the material. The author concludes that the only way to end ivory trafficking effectively is to reduce demand. RS

## DIAMONDS

**Angola: Diamond production on the rise.** N. Ford, *African Business*, No. 309, 2005, pp. 54–55.

With the end of Angola's civil war, the country's state-owned diamond administration agency, Endiama, is assuming a wider role in economic growth. Endiama expects the country's yearly diamond production to nearly double by 2007, to 12 million carats from the 6.5 million carats mined in 2004. With the increased yield, revenues would be an estimated \$2.2 billion. Part of this increase will come from new production from both alluvial and kimberlite mines. However, illegal mining and smuggling of diamonds is still costing the Angolan government an estimated \$375 million yearly. The government is attempting to crack down on the 250,000 illegal miners who are responsible for this production. RS

**Colour in diamond—yellow.** J. Chapman, *Rough Diamond Review*, Part I. No. 7, 2004, pp. 42–44.  
**Diamond colour origins. Part II.** No. 8, 2005, pp. 23–26.

The origin of color in diamonds is an important research

topic in gemology, with both scientific and economic implications. This two-part article describes how impurities and dislocations, and the complex relationship between them, can produce yellow, green, blue, brown, pink, and other colors in diamonds, both naturally and artificially. The general mechanism by which diamonds display bodycolor involves the selective absorption of light by atomic-level defects. Impurities like nitrogen and boron in the diamond lattice can lead to such selective absorption, resulting in yellow and blue coloration, respectively. The tendency for nitrogen in diamond to aggregate into different types of clusters (resulting in A, N3, and B centers) is explained, as is its effect on color.

In addition to impurity elements, shear stresses on a diamond can distort the lattice or displace atoms in the lattice to cause color. Subjected to this plastic deformation, carbon atoms can be dislodged from the lattice to create vacancies or dislocations, or alter impurity defects, which may create colors such as brown and pink. Radiation can create vacancies leading to pale blue or green diamonds. Other color-causing agents (e.g., nickel) or treatments (e.g., annealing and different types of irradiation) also are discussed, often with respect to synthetic diamonds. DMK

**Geosurvey techniques in offshore diamond mining. I.** Stevenson [ian.stevenson@debeersgroup.com] and L. Ricketts, *Hydro International*, Vol. 8, No. 9, 2004, pp. 26–29.

A 1,400 km stretch of continental shelf off the west coast of southern Africa hosts the world's largest marine diamond placer deposit. Storm-dominated seas contribute to challenging working conditions. Ultra-high resolution geophysical data obtained with an AUV (autonomous underwater vehicle) are used to improve the geologic understanding of target areas. This enables more precise prediction of diamond concentrations and therefore a reduced cost per square meter of seabed mined.

For survey purposes, the continental shelf is divided into three regions, each requiring mapping and mining strategies best suited to its specific terrain. The *inner shelf platform* extends from the present-day coastline to about 2 km offshore and has water depths of 0–30 m. Diamondiferous gravels are concentrated in depressions eroded into the exposed bedrock and are extracted with the use of diver-assisted suction hoses operated from small surface vessels. The *inner shelf slope* extends 2–5 km offshore and has water depths of 30–70 m; diamondiferous gravels are located at the base of the sediment layers. The *middle shelf* region extends 5–150 km offshore in water 70–200 m deep, and this is where the majority of offshore mining activity occurs. Here, diamondiferous gravels (usually <1 m thick) are mined using a vertical extraction method involving a 7-m-diameter drill or a remote-operated crawler with a suction head. EF

**Interpreting diamond morphology.** V. Afanasiev, N. Zinchuk, V. Sonin, and E. Semenets, *Rough Diamond Review*, **Part I.** No. 5, 2004, pp. 30–33; **Part II.** No. 7, 2004, pp. 26–27.

*Typomorphism* is the ability of a mineral to reflect its formation conditions by means of its structural, morphological, and/or chemical characteristics. Russian mineralogists have found that such characteristics (e.g., unique morphological and surface features) are of great value in interpreting the original growth, post-growth, and emplacement conditions of diamonds, and for diamond prospecting on the Siberian platform.

Although the primary habit of diamond is the octahedron, modifications to this shape are both common and significant. After growth, the morphology of diamonds may be modified while residing in the medium that formed them and/or during the processes that eventually brought them to the surface. Accordingly, two types of post-growth alteration are recognized: “dry” (anhydrous, without H<sub>2</sub>O) and “wet” (hydrous, with H<sub>2</sub>O). Dry morphogenesis is characterized by the rounding of growth layers, the development of parallel striations near octahedral edges, and the formation of inverted trigons. These characteristics reflect post-growth activity in the host medium before entering the transport melt. Wet morphogenesis is characterized by the rounding of octahedral edges leading to dodecahedral (dissolution) forms and occurs within the transport melt.

Post-magmatic conditions, of which mechanical wear during the formation of alluvial deposits is the most important, can also lead to distinctive morphologies. Although mechanical wear only slightly alters morphology, this process is very important from a typomorphic perspective. Mechanical wear is seen in two main forms, striated surfaces and “icicle” features, both of which result from mechanical polishing and abrasion of crystals mainly at their edges and corners. Striated surfaces appear as regular patterns of pitting or wear, whereas icicle features refer to smooth surfaces (with the appearance of ice) that suggest such diamonds are very old and may have been through numerous cycles of erosion and deposition.

Typomorphic features (including those obtained by infrared spectroscopy and trace-element analysis) offer the potential for determining the exact mine from which a diamond originated. DMK

**The roles of primary kimberlitic and secondary Dwyka glacial sources in the development of alluvial and marine diamond deposits in southern Africa.** J. M. Moore [j.moore@ru.ac.za] and A. E. Moore, *Journal of African Earth Sciences*, Vol. 38, No. 2, 2004, pp. 115–134.

It is well known that the source of most of the alluvial diamonds in southern Africa is a number of Cretaceous (145–65 million years [My]) kimberlites that have been deeply eroded. Diamonds liberated from these kimberlites

have been concentrated into important deposits in major drainages (e.g., the Vaal River) in a variety of settings along their routes westward to the Atlantic Ocean. Less well known is the role glaciation played in the development of the alluvial deposits during the earlier Carboniferous/Permian periods (360–250 My).

The Dwyka glaciation (a 30 My period) occurred approximately 300–270 My ago when southern Africa was situated much closer to the South Pole. The authors provide convincing evidence that this glaciation eroded older kimberlites in certain areas (e.g., those where the Venetia and Premier mines were eventually developed) while also reworking diamond-bearing river sediments existing at the time in other areas. The glacial sediments (the Dwyka Group) themselves were later eroded, re-releasing diamonds into younger drainage systems. Some of these diamonds were transported to the west coast and incorporated into beach sediments. Thus, southern African diamonds found in modern river valleys or beach sediments likely had their origins from a number of different kimberlite sources. Application of this model could lead researchers to areas of southern Africa previously thought to be unpromising for diamonds (e.g., areas where the Dwyka Group has not been heavily eroded), and it might also help explain ore-grade and diamond-quality variability in current mining operations.

KAM

**Spectroscopic studies on transition metal ions in colored diamonds.** Y. Meng, M. Peng, and W. Chen, *Spectroscopy and Spectral Analysis*, Vol. 24, No. 7, 2004, pp. 769–774 [in Chinese with English abstract].

The forms and behaviors of transition-metal ions, such as Ni, Co, and Fe, in both natural and synthetic diamonds have been extensively investigated, mainly because these elements are used as catalysts in the growth of diamonds by high-pressure, high-temperature (HPHT) techniques. Ni and Fe occur as interstitial or substitutional impurities in the diamond lattice, and form complexes with nitrogen in both natural and HPHT synthetic diamonds. Interstitial Co has been reported only in synthetic diamonds. In this article, the spectroscopic characteristics of the transition metals, and the forms in which they occur, were studied in six colored natural and synthetic diamonds (one light bluish gray diamond from Argyle, Australia; two “chameleon” diamonds from Indonesia; and three HPHT synthetic diamonds from Russia that were orange-yellow, light blue, and dark red).

SEM-EDS revealed Ni in all the samples. Co-related optical centers were reported for the first time in the chameleon diamonds, based on photoluminescence spectra. These spectra were similar to those recorded in annealed HPHT synthetic diamonds with Co-related optical centers. Ni-related optical centers and H3 centers also were detected in the chameleon diamonds, suggesting that they may have been subjected to natural irradiation

and high-temperature annealing. EPR (electron paramagnetic resonance) spectroscopy revealed some nitrogen-related peaks and some transition-metal elements (mainly Ni) related to fine structures in both the natural and the synthetic diamonds. The Argyle sample showed two Ni-related peaks centered at 785 and 872 nm, as well as seven unrecognized peaks that may be assigned to a Ni-N complex. TL

**Three historical “asteriated” hydrogen-rich diamonds: Growth history and sector-dependent impurity incorporation.** B. Rondeau [rondeau@mnhn.fr], E. Fritsch, M. Guiraud, J.-P. Chalain, and F. Notari, *Diamond and Related Materials*, Vol. 13, No. 9, 2004, pp. 1658–1673.

Three diamond cleavage plates (~0.13–0.15 ct), each exhibiting symmetrical lobe- or petal-like color zones, were investigated to gain a better understanding of their growth structure and history. These historic type Ia diamonds, catalogued as part of the collection of the National Museum of Natural History in Paris between sometime before 1822 and 1844, were studied by the famous 19th century French mineralogists René-Just Haüy and Alfred Descloizeaux. For the present study, the samples were reexamined by spectroscopic, imaging, and luminescence techniques. Two of the samples displayed either gray or brown lobe-shaped sectors forming a three-fold arrangement in a near-colorless or light brown matrix, while the third exhibited dark brown lobes in a six-fold pattern in a light brown matrix. Each diamond is an example of contemporaneous growth of both cuboid (lobes) and octahedral (matrix) sectors, but with different amounts of nitrogen and hydrogen.

The various shapes of the lobed patterns in the three samples reflect a continuous variation in the relative growth rates of the two kinds of sectors. The UV-Vis spectra of all three samples displayed increasing absorption toward the UV region, which explains the gray or brown color. One sample also displayed a 415 nm band (the N3 center) in the octahedral sector and numerous weak absorption bands between 350 and 570 nm (due to H) in the cuboid sector. IR spectra revealed enriched H and N concentrations in both sectors, but H was greater in the cuboid sectors (where it inhibited nitrogen aggregation), whereas N was greater in the octahedral sectors. Additional details of the IR and Raman spectra are presented, along with a discussion of the stages of incorporation of N and H during diamond formation. Hydrogen appeared to be incorporated in several different structural sites. JES

## GEM LOCALITIES

**Cultured pearl resources and markets in China.** H. Zhang and B. Zhang, *Journal of Gems and Gemmology*, Vol. 6, No. 4, 2004, pp. 14–18 [in Chinese with English abstract].

This article was written by authors from the National Gems & Jewelry Information Center, Beijing, to provide producers and consumers with the latest statistics on the Chinese cultured pearl industry. Three main types of cultured pearls are being produced in China: saltwater, freshwater tissue-nucleated, and freshwater bead-nucleated.

The saltwater cultured pearl farms are located mainly in the provinces of Guangdong, Guangxi, and Hainan. Total production was ~42 tonnes in 2003, of which Guangdong produced the most (30 tonnes), followed by Guangxi (10 tonnes) and Hainan (2 tonnes).

The culturing region for Chinese freshwater tissue-nucleated cultured pearls extends over six provinces along the Yangtze River. Zhejiang (32%) is the most important, followed by Jiangsu (23%), Hunan (17%), Anhui (13%), Hubei (8%), and Jiangxi (7%). Total production in 2003 was 1,400 tonnes. Zhuji in Zhejiang Province, and Weitang and Suzhou in Jiangsu Province, are the largest and most important trading centers for this type of cultured pearl. Jiangxi Province is the most important locality for freshwater bead-nucleated cultured pearls, with a total production in 2003 of 160 tonnes. TL

**Emeralds of the main world origins.** E. P. Melnikov, A. V. Vasiliev, and G. N. Pilipenko, *Gemological Bulletin*, No. 11, 2004, pp. 7–16 [in Russian with short English abstract].

The gemological properties (S.G., R.I., dispersion, and birefringence) and mineral inclusions in emeralds from various worldwide deposits are summarized in three tables. Five main emerald-bearing belts and provinces are characterized: Colombian, Brazilian, South African, Uralian, and Central Asian. Also included are specific data for emeralds from Afghanistan, Australia, Austria, Madagascar, and Zambia.

In general, good-quality emeralds originate from two genetic types of deposits: a metasomatic greisen type in ultramafic rocks (Uralian), and a hydrothermal type characterized by veins in black shales and carbonate rocks (Colombian). The concentrations of minor elements differ between the types. Light green Uralian emeralds contain more Cr (up to 0.1 wt.%) than do those from Colombia (0.01–0.06 wt.%), but dark green emeralds from the Urals contain up to 0.33 wt.% Cr, whereas comparable Colombian stones have up to 0.43 wt.% Cr. Fe and V concentrations also differ: up to 0.06 and 0.66 wt.%, respectively, in Colombian emeralds, compared to 0.54 and ~0.1 wt.%, respectively, in Uralian stones.

Visible-range absorption spectroscopy was performed on eight samples (along the ordinary and extraordinary rays), including one synthetic emerald containing only Cr as a chromophore. Two transmission windows were apparent in all these stones, one in the green region (480–540 nm) and one in the red region (>680 nm); a narrow Cr line near 680 nm was very characteristic of the extraordinary ray. The spectra of hydrothermal-type emer-



alds from Afghanistan were close to that of the synthetic emerald. The Colombian stones tested were colored mainly by V; Cr lines near 800 nm were absent. The spectra of the Uralian emeralds did show Cr lines near 800 nm, but absorption in the red region of the spectrum was stronger (such stones may show no reaction under the Chelsea filter). Emeralds from Zambia and Madagascar may show strong "aquamarine" lines near 800 nm and, in addition, a wide band near 650 nm (for the extraordinary ray only). These stones contain appreciable quantities of Fe and showed no reaction under the Chelsea filter.

BMS

**Emeralds from the Panjshir Valley (Afghanistan).** J. Fijal, W. Heflik, L. Natkaniec-Nowak, and A. Szczepaniak, *Gemmologie: Zeitschrift der Deutschen Gemmologischen Gesellschaft*, Vol. 53, No. 4, 2004, pp. 127–142.

Twelve emerald crystals from the Panjshir Valley in Afghanistan were studied using various gemological and mineralogical techniques. These emeralds were compared to those from around the world on the basis of results from macro- and microscopic observations; chemical, X-ray, and infrared spectroscopic analyses; and new oxygen isotope data. The emeralds from the Panjshir Valley probably formed from metasomatic alteration associated with regional metamorphism. They crystallized at temperatures in the range of 220–350°C in quartz-ankerite veins that intersect marbles and talc-carbonate schists. The low temperatures of formation and the oxygen isotope data suggest that the emeralds were formed by thermochemical reactions similar to those associated with the formation of the Brazilian, Colombian, and Pakistani (Swat-Mingora) emerald deposits. EF

**The Lened emerald prospect, Northwest Territories, Canada: Insights from fluid inclusion and stable isotopes, with implications for northern Cordilleran emerald.** D. D. Marshall [marshall@sfu.ca], L. A. Groat, H. Falck, G. Giuliani, and H. Neufeld, *Canadian Mineralogist*, Vol. 42, No. 5, 2004, pp. 1523–1539.

In 1997, emerald and green beryl were found at the Lened property in the Northwest Territories, approximately 55 km northwest of the town of Tungsten in the Logan Mountains. Crystals up to 2.5 cm long (rarely of gem quality) formed in quartz-carbonate veins that are hosted within a fractured garnet-diopside skarn. Both the veins and the skarn are the result of contact metamorphism related to the intrusion of the mid-Cretaceous (93 My) Lened granitic pluton into Proterozoic sedimentary host rocks (shales and limestones).

The veins vary in thickness up to about 50 cm, and nearly half of them contain some beryl or emerald. Chemical analyses by LA-ICP-MS indicate that the principal chromophore is V, with little or no Cr (data from

two crystals gave 830 and 1444 ppm V, and only 8 and 14 ppm Cr). A CO<sub>2</sub>-bearing aqueous brine is present within multiphase fluid inclusions along healed fractures in the emerald. Emerald formation is estimated to have occurred at pressures up to 320 MPa and temperatures between 200 and 610°C. Preliminary stable isotope data indicate that the emerald is derived from a magmatic source. The Cretaceous granitic rocks are believed to be the source of Be, while V was extracted from the shales. This deposit has some geologic characteristics and conditions of formation similar to those at the Tsa Da Glisza (or Regal Ridge) emerald occurrence in the Yukon. JES

**Gemstones in Vietnam: A review.** P. V. Long [vggc@fpt.vn], G. Giuliani, V. Garnier, and D. Ohnenstetter, *Australian Gemmologist*, Vol. 22, No. 4, 2004, pp. 162–168.

In the Luc Yen, Yen Bai, and Quy Chau areas of northern Vietnam, ruby and sapphire are hosted by primary deposits (metamorphic rocks) and in placers (associated with gem spinel and garnet). In southern Vietnam, the occurrence of sapphires is related to alkaline basalts, with blue sapphires being of economic significance. Here the sapphires are recovered from placer deposits along with gem zircon and peridot. Elsewhere in Vietnam, aquamarine, beryl, topaz, tourmaline, quartz (amethyst, citrine, and smoky), chalcedony, fluorite, opal, jadeite, nephrite, amazonite, and tektites are exploited to various degrees. Several types of cultured pearls are being produced in four provinces. Rubies, sapphires, and cultured pearls are presently the main gem materials of commercial importance in Vietnam. RAH

**Migration of the Mendocino Triple Junction and the origin of titanium-rich mineral suites at New Idria, California.** M. R. Van Baalen [mvb@harvard.edu], *International Geology Review*, Vol. 46, No. 8, 2004, pp. 671–692.

The discovery of cinnabar ore in the New Idria District of central California in 1851 began over a century of profitable mercury mining. This, combined with the subsequent exploration for oil in 1915, led to the discovery of several useful minerals including magnesite, chromite, various gems, and chrysotile (asbestos). Data on the formation and composition of Ti-rich mineral suites associated with the New Idria serpentinite are presented along with a new petrologic model for their formation. These peculiar minerals, which include Ti-rich andradite garnets and benitoite, underwent blueschist and lower greenschist metamorphism associated with the tectonic passage of the Mendocino Triple Junction and emplacement of the serpentinite ~12 million years ago. Previous workers had suggested that fluid migration introduced several of the elements necessary for the formation of the unusual mineral suites. However, more recent studies have shown that the solubilities of these elements (e.g., Ti, Al, and Zr) are extremely low and would require fluid transport over long distances.

The new model calls for isochemical metamorphism (i.e., no change in bulk composition is required) of pre-existing pyroxenite veins, which contain all the required components necessary for the formation of Ti-rich mineral suites. The author suggests that benitoite, California's state gem, formed by metamorphism of blocks of Franciscan greenstone within the serpentinite at lower greenschist conditions. EF

**Opals from Slovakia ("Hungarian" opals): A re-assessment of the conditions of formation.** B. Rondeau [rondeau@mnhn.fr], E. Fritsch, M. Guiraud, and C. Renac, *European Journal of Mineralogy*, Vol. 16, No. 5, 2004, pp. 789–799.

Slovakian opals found in an andesitic host rock in the Dubník area, near Košice (which was part of Hungary until the end of World War I), are believed to have formed by water circulation during a tectonic event. Their physical properties were investigated by X-ray diffraction (opal-A), Raman spectroscopy (main peak at 437  $\text{cm}^{-1}$ ), and scanning electron microscopy (relatively large silica spheres of 125–270 nm in diameter). Surprisingly, these properties are usually associated with opals found in sedimentary deposits, not volcanic rocks. Preliminary oxygen isotope data indicate a high  $\delta^{18}\text{O}$  value (31‰) for both Slovakian ("volcanic-type") and Australian ("sedimentary-type") opals, consistent with temperatures of formation of less than 45°C. In contrast, Mexican ("volcanic-type") opal-CT shows a lower  $\delta^{18}\text{O}$  value (13‰) that is consistent with formation at a higher temperature, possibly up to 190°C. Thus, temperature is proposed as the control on the opal's physical properties, rather than the nature of the host rocks. RAH

**Pezzottaite  $\text{Cs}(\text{Be}_2\text{Li})\text{Al}_2\text{Si}_6\text{O}_{18}$ : A spectacular new beryl-group mineral from the Sakavalana pegmatite, Fianarantsoa province, Madagascar.** F. C. Hawthorne, M. A. Cooper, W. B. Simmons, A. U. Falster, B. M. Laurs, T. Armbruster, G. R. Rossman, A. Peretti, D. Günter, and B. Grobéty, *Mineralogical Record*, Vol. 35, No. 5, 2004, pp. 369–378.

Pezzottaite is a pink to purplish red, Cs-rich beryl-group gem mineral that has been found in small quantities in Fianarantsoa Province, central Madagascar. It formed within a limited area of the pocket zone of the Sakavalana pegmatite as tabular crystals or irregularly shaped flat masses along with quartz, feldspar (cleavelandite and amazonite), tourmaline, and other minerals. This article presents a detailed description of this relatively new gem mineral, including information on its physical and optical properties, crystallographic and X-ray diffraction data, infrared spectra, and chemical composition. The mineral is uniaxial negative, with refractive indices of  $\epsilon = 1.601\text{--}1.611$  and  $\omega = 1.612\text{--}1.620$ , and an observed density of 2.97  $\text{g}/\text{cm}^3$  (calculated 3.06  $\text{g}/\text{cm}^3$ ); hardness is 8. It is inert to long- and short-wave UV radiation, and is dichroic

in hand specimen ( $\epsilon$  = purplish pink to pinkish purple, and  $\omega$  = pink-orange). Its relationship to other members of the beryl group is described. Several tens of kilograms of pezzottaite of varying quality were recovered at this locality in the late 2002, with little subsequent production. JES

**Pezzottaite von Ambatovita, Madagaskar—eine abenteuerliche Entdeckung [Pezzottaite from Ambatovita, Madagascar—An adventurous discovery].** F. Pezzotta [fpezzotta@yahoo.com], *Lapis*, Vol. 30, No. 5, 2005, pp. 26–30.

In this article, the mineralogist after whom the new gem mineral pezzottaite is named, and who participated in its analysis and description, relates the history of pezzottaite from its first appearance in Antananarivo in November 2002 to its acknowledgment as a new mineral of the beryl group. He describes the flurry of activity following the discovery, the difficult conditions under which the stones were mined, the mineral paragenesis, and the geologic setting of the pezzottaite-bearing pegmatite. This same issue of *Lapis* also contains a detailed description of pezzottaite and its mineralogical properties ("Steckbrief Pezzottaite," by R. Hochleitner and S. Weiss, pp. 9–11). Both articles contain lavish illustrations, a map, and crystal drawings. RT

**Relationship between nanostructure and optical absorption in fibrous pink opals from Mexico and Peru.** E. Fritsch [fritsch@cnsr-immn.fr], E. Gaillou, M. Ostroumov, B. Rondeau, B. Devouard, and A. Barreau, *European Journal of Mineralogy*, Vol. 16, No. 5, 2004, pp. 743–752.

Translucent pink opals from Mexico (Mapimí and the state of Michoacán) and Peru (Acarí area, near Arequipa) are opal-CT, containing 10–40% palygorskite, as demonstrated by X-ray diffraction, infrared spectroscopy, and S.G. measurements. As seen by electron microscopy, these opals have an unusual fibrous nanostructure (with bunches of fibers 20–30 nm in minimum diameter) related to the fibrous nature of the palygorskite crystals. This is in contrast to the usual perfect stacking of 150–300 nm silica spheres. A complex absorption centered at about 500 nm is the cause of the pink color. It is suggested that the absorption is due to quinone fossil products associated with the phyllosilicate fibers. The opal-CT–palygorskite–quinone association is a geologic marker for a specific environment, presumably an ancient lake in a volcanic region. RAH

**Role of fluorine in the formation of the Mananjary emerald deposits (eastern Madagascar).** B. Moine [moine@cict.fr], C. C. Peng, and A. Mercier, *Comptes Rendus Geoscience*, Vol. 336, No. 6, 2004, pp. 513–522.

The Mananjary emerald deposits are hosted by phlogopite-rich rocks that formed through metasomatic alteration of

ultrabasites at about 500°C and 2 kbar. F- and Be-rich fluids responsible for the emerald crystallization probably originated from granites and granitic pegmatites that were emplaced during the formation of the Ifanadiana-Angavo shear zone roughly 550–500 million years ago. Thermodynamic modeling explains the role of fluoride complexes in the transport of Be. The solubility of Be increases as the amount of F in aqueous solution increases. At the point of crystallization of an F-rich mineral (F-phlogopite in this case), the associated Be becomes unstable in solution and begins to crystallize minerals that are able to incorporate it into their structure (beryl in this case). Sufficient Cr within the ultrabasites enabled the formation of emerald.

EF

## INSTRUMENTS AND TECHNIQUES

**In situ Raman spectroscopic investigations of the adorning gemstones on the reliquary Heinrich's Cross from the treasury of Basel Cathedral.** I. Reiche [ina.reiche@culture.gouv.fr], S. Pages-Camagna, and L. Lambacher, *Journal of Raman Spectroscopy*, Vol. 35, No. 8–9, 2004, pp. 719–725.

A nondestructive study of the gems on Heinrich's reliquary cross, currently kept in Berlin at the Museum of Applied Arts (Kunstgewerbemuseum), was performed using a mobile Raman microspectrometer. Analyses were made with a fiber-optic attachment on the Raman analyzer directly in the museum, so there was no need to move the object. This cross, which dates from the first quarter of the 11th century, is considered one of the most precious relics in the treasury of Basel Cathedral. Sixty-eight "gems" are mounted on both the front and back of the cross. Most were found to be glass "paste" or varieties of quartz, although some garnets, sapphires, and rubies also were identified; 11 gems could not be identified unambiguously. It remains unclear whether the gem materials currently in the cross are the original ones—chosen mainly for their color and not necessarily for their value—or if they are later replacements for more valuable gems.

Several factors contributed to an overall lower quality of analyses than could be obtained with a conventional Raman microspectrometer in a laboratory. First, an instrument using fiber-optic coupling with a remote head has lower laser power, so it did not allow for the flexibility needed to work with several highly fluorescent gems. Second, older, historic samples often have irregular surfaces that result in poor analyses. Last, the authors were not allowed to clean the gems with solvents; therefore, organic or other residues could lead to additional peaks in the spectra. This study, while important for demonstrating the capabilities of mobile Raman spectroscopy, also shows the importance of coupling optical observations with spectroscopic results for gem identification.

EF

### The identification of carving techniques on Chinese jade.

M. Sax [msax@thebritishmuseum.ac.uk], N. D. Meeks, C. Michaelson, and A. P. Middleton, *Journal of Archaeological Science*, Vol. 31, No. 10, 2004, pp. 1413–1428.

Jade carving in China dates from before 5000 BC. Thus far, the details of ancient jade-carving techniques have remained relatively unclear. This study resolves some of those issues. Methods developed to investigate known lapidary techniques used on quartz cylinder seals from the Near East were applied to eight Chinese nephrite jade artifacts. The artifacts were from three different historical periods: the Neolithic Hongshan and Liangzhu cultures (4th to 3rd millennia BC), the Western and Eastern Zhou dynasties (11th to 3rd centuries BC), and the Ming and Qing dynasties (14th to 20th centuries AD). The carving characteristics of the artifacts, observed using a binocular microscope and a scanning electron microscope, included surface texture, the shape in plan view, and the longitudinal depth of the engraved feature. The morphology of the surrounding surfaces was also considered.

Six carving techniques were identified: drilling, wheel-cutting, sawing, flexible string sawing, riffling, and point or blade abrasion. Most of the artifacts retained traces of the original tool marks that appear to have been produced mainly during the secondary stages of shaping and incising the objects; weathering may be responsible for the absence of ancient tool marks on one sample. The techniques employed in this study have the potential to be applied to the development of a chronology of Chinese jade-carving techniques from the Neolithic to the modern era.

AI

**Seeing stress in diamonds.** K. Pope, *Rough Diamond Review*, No. 5, 2004, pp. 41–43.

Internal strain is an important factor in diamond fashioning, as localized strain complicates cutting and may even result in an unintended fracture. Inclusions, "knots," plastic deformation, or restrictions during crystal growth cause distortions in the crystal lattice (i.e., internal strain). This can be observed as anomalous birefringence, familiar to gemologists as the banded, colored patterns seen between crossed polarizers. This article describes how the time-consuming historic manual measurement and analysis of internal strain based on birefringence with the use of compensators (e.g., a quartz wedge or Berek compensator) has been superseded. Quantitative birefringence data can now be obtained in a matter of seconds with the Metripol device. This automated instrument consists of a motorized rotating polarizer, a circular analyzer assembly, a CCD (charge-coupled device) camera, and a computer with analytical software. This new imaging technique, in addition to helping reduce the risk of an unintended fracture during fashioning, has potential application in several areas of diamond research.

DMK



## SYNTHETICS AND SIMULANTS

**The identification properties of synthetic hydrothermal red, green, and blue beryl.** M. B. Kopchikov and Yu. B. Shelementiev, *Gemological Bulletin*, No. 11, 2004, pp. 17–22 [in Russian with short English abstract].

A collection of 23 faceted samples (0.05–0.30 ct) of hydrothermal synthetic beryl (12 red, 5 green, and 6 blue) were studied using a variety of standard and advanced techniques to determine their diagnostic properties. The crystals were grown at the Institute of Petrography and Mineralogy in Novosibirsk, Russia. This is the first time that the properties of synthetic beryl from this source have been reported.

No gas-liquid inclusions or color zoning were observed, contrary to what is frequently the case in natural beryl. An infrared peak at  $3701\text{ cm}^{-1}$  was a diagnostic feature for all these hydrothermal synthetics; this peak is not found in natural beryl. There were also distinct differences in the visible-range absorption spectra of all three colors of synthetic beryl compared to their natural counterparts.

Nickel (0.1–0.4 wt.% NiO) occurred in all the synthetic beryls. Copper was present in the green (0.92–1.27 wt.% CuO) and blue (0.29–0.35 wt.% CuO) varieties. S.G. and R.I. values were comparable to those found in natural beryl. When exposed to long-wave UV radiation, the synthetic aquamarines had weak white-yellow luminescence, and the synthetic red beryls had red luminescence of variable intensity; luminescence in the corresponding natural beryls is generally absent or very weak. UV fluorescence was absent in the green synthetic beryl samples due to their high Fe content. BMS

**The nature of channel constituents in hydrothermal synthetic emeralds.** R. I. Mashkovtsev [rim@uiggm.nsc.ru] and S. Z. Smirnov, *Journal of Gemmology*, Vol. 29, No. 4, 2004, pp. 215–227.

Natural emeralds and hydrothermally grown synthetic emeralds have become increasingly difficult to separate due to improving techniques for growing the synthetics. Since their physical properties overlap, microscopic examination of their inclusions is important. However, if an emerald is “clean” or does not contain diagnostic inclusions, nondestructive techniques based on certain distinctive minor impurities can be used for identification. This article illustrates how IR spectroscopy and EDXRF analysis were used to separate Biron (Australian), Regency (Linde), and Tairus (Russian) hydrothermally grown synthetic emeralds from one other and from natural Ural Mountains emeralds. For example, hydrothermal synthetic emeralds are grown using ammonium halides in an acidic (HCl) medium, so the detection of chlorine and ammonium molecules as a structural component confirms this origin. In Tairus synthetic emeralds, Cu and Ni form impurities that are derived from the walls of the steel

autoclaves in which they grew. The amounts of Cr, V, and Fe (determined by EDXRF), as well as the type I and type II water peaks (determined by IR spectroscopy), also are useful parameters for distinguishing natural from hydrothermal synthetic emeralds from various sources. WMM

## TREATMENTS

**Meaning of ions diffusion coefficient in sapphire diffusion heat treatment.** R. Yang, D. Yu, and J. Zhao, *Journal of Tongji University (Natural Science)*, Vol. 32, No. 9, 2004, pp. 1145–1148 [in Chinese with English abstract].

Blue color enhancement of sapphire by surface-diffusion processes at high temperatures has been reported since the 1980s. However, most treatment processes are based on “trial and error.” In this article, the diffusion coefficients of Fe and Ti ions in sapphire crystals calculated during various treatment conditions are presented. Colorless and light blue sapphires were treated with (unspecified) Fe- and Ti-containing chemicals in an aluminum oxide crucible at a temperature of 1,800–1,900°C for up to 72 hours at a Thai jewelry company. The thickness of the diffusion layer was measured from samples cut into 0.8 mm thick plates. The concentrations of Fe and Ti in different layers, starting from the outer surface of the samples, were determined by electron-microprobe analysis.

The diffusion coefficients of Fe and Ti in sapphire are mainly controlled by temperature, duration of the treatment, thickness of the diffused layer, and the initial concentrations of  $\text{Fe}^{2+}$  and  $\text{Ti}^{4+}$  ions in the chemical additives. However, at certain temperatures, the diffusion coefficients of Fe and Ti ions were essentially constant, regardless of variations in the duration. The diffusion coefficient of Ti ions was much greater than that of Fe ions, being  $6.57 \times 10^{-9}\text{ cm}^2 \cdot \text{s}^{-1}$  and  $1.62 \times 10^{-9}\text{ cm}^2 \cdot \text{s}^{-1}$ , respectively. Using these coefficients in conjunction with specified temperatures and duration times, it is possible to control the thickness of the diffusion layer in sapphire. These coefficients may also be useful toward lightening dark colored sapphires, such as those from Shangdong, China. TL

**A treatment study of Brazilian garnets.** S. G. Eeckhout, A. C. S. Sabioni, and A. C. M. Ferreira, *Journal of Gemmology*, Vol. 29, No. 4, 2004, pp. 205–214.

Reports of gem treatments are widespread in the literature but very few have been published on garnets. This article reports on the enhancement of several types of mostly gem-quality Brazilian garnets (pyrope, almandine-pyrope, almandine-spessartine, and grossular), primarily from pegmatite and alluvial occurrences in the states of Minas Gerais and Rio Grande do Norte. The authors determined the enhancement response of these garnets to heat treatment in air, and in oxidizing (oxygen saturated), inert

(argon saturated), and reducing (hydrogen saturated) atmospheres, at various temperatures (600–1000°C) and durations (generally 4–24 hours). The response of pale yellow grossular to diffusion treatment (900°C for 44 hours) using oxides of Fe, Cr, and Co also was investigated.

Following heat treatment in both the oxidizing and inert atmospheres, almandine-spessartine and pyrope (containing 9.12 wt.% FeO) became opaque and were coated with a “silvery skin,” caused by the formation of hematite. The higher the iron content of the stone, the more noticeable the silvery luster. The iron-rich (i.e., almandine-containing) stones became opaque and had a burned, charcoal-like appearance after heating in air at 1,000°C for 4 hours or 900°C for 24 hours. Grossular samples turned orange after heating. No changes were observed in any sample heated in the reducing environment at 800°C for 4 hours.

Diffusion of Fe and Cr produced an orange layer on the grossular samples, whereas diffusion of Co produced a green layer. In general, longer treatment times and higher temperatures resulted in a greater thickness of the diffused color. WMM

## MISCELLANEOUS

**Comments on Canada’s national diamond strategy.** R. Taplin [rtaplin@mccarty.ca] and T. Isaac, *Journal of Energy & Natural Resources Law*, Vol. 22, No. 4, 2004, pp. 429–449.

Canada has become one of the world’s primary diamond producers, which has prompted the federal and several provincial governments to draw up strategies that will (1) maximize benefits for Canadians; (2) develop cooperation between various governments, mining companies, and local populations; and (3) encourage investment and development in all sectors of the industry.

The primary policy dilemma facing Canada’s industry is developing local diamond-manufacturing operations. The governments want to increase employment and local participation in the diamond industry, but mining companies claim that enforced supply to these operations results in diminished profits. The companies also claim that this deters future exploration and development. The current national policy is to make such supply agreements voluntary; however, the article cites an example of strong pressure from the government of the Northwest Territories to get BHP Billiton to offer 10% of its production from the Ekati mine to local operations. More stringent requirements could run afoul of the North American Free Trade Agreement and various other treaties and regulations.

The diamond industry and government also disagree over “Canadian Diamond” branding efforts. The government believes that a Canadian diamond origin could carry a premium in the market, while many in the industry do not. This has led to a debate over whether diamonds

marked with that national origin must, indeed, be mined there; the Canadian government’s definition says they must. [Editor’s note: Under U.S. law, the “country of origin” for a faceted diamond is the country in which it was polished, not where it was mined; see Spring 2005 Gem News International, p. 71.] Mining regulations and aboriginal land rights also are discussed. RS

**Global governance and conflict diamonds: The Kimberley Process and the quest for clean gems.** J. A. Grant [andgrant@dal.ca] and I. Taylor, *The Round Table*, Vol. 93, No. 375, 2004, pp. 385–401.

This paper recounts the early efforts of non-governmental organizations (NGOs) to pressure the world diamond industry into adopting controls to halt the trade in conflict diamonds. Two NGOs, Global Witness and Partnership Africa Canada, were instrumental in bringing this problem to world attention in the late 1990s. At the end of 1999, the NGOs began an awareness campaign among European consumers called Fatal Transactions. Shortly afterward, the U.S. Congress began debating legislation to ban conflict diamonds.

Early in 2000, a number of diamond-producing nations convened in Kimberley, South Africa, to discuss a series of controls on diamonds to help stop the conflict diamond trade. This was the beginning of the Kimberley Process (KP). The United Nations endorsed the KP in December of that year. The diamond industry formed the World Diamond Council to develop the tracking mechanism and self-regulation routines needed to put the KP into action.

The article concludes that, while the Kimberley Process and industry efforts show a commitment on the part of governments and the industry to stop conflict diamonds, challenges remain in the form of potentially compromised KP certificates of origin, the willingness of the trade to exercise due diligence, and the priorities of diamond-producing governments (particularly in areas with alluvial diamond mining). RS

**Improving your opal cutting.** P. B. Downing, *Lapidary Journal*, Vol. 57, No. 11, 2004, pp. 25–28.

Four common problems encountered in opal cutting are addressed:

1. *Making shoulders.* For an opal to be properly set, it must have shoulders that allow the metal setting to solidly grip the stone. This requires a slight (10–15°) taper (narrower at the top) in the middle third of the shoulder; the bottom third of the shoulder is straight, and the top third curves into the dome.
2. *Scratches and polish.* The most efficient way to remove scratches is to sand across them with successively finer grits. Sanding with the scratches makes them broader and deeper. To bring out hard-to-see scratches during the medium sanding process, the stone should be paint-

ed with a black marker and the ink wiped before it dries. The ink will be removed from a smooth surface but will remain in scratches. During the fine sanding stage, tiny scratches can be seen on the surface of dry samples by noting (a) without magnification, the reflection of the bulb of the cutting lamp; or (b) with 3×–10× magnification, straight lines with sharp definition. A good polish is essential to bring out the play-of-color. The smoother the surface, the more color will be returned to the eye.

3. *Perfecting the dome.* Domes on opals should have a smooth curvature with no flat spots. To achieve the best curvature, the opal should be sanded across flat spots with a medium grit followed by a fine grit.
4. *Dome height.* Low domes are best for stones with a highly directional color pattern, whereas higher domes are used for stones with a nondirectional or thick seam of color.

Analyzing the fire in opal rough is the first step to cutting any opal to bring that fire to the surface.

MC

**War, peace and diamonds in Angola: Popular perceptions of the diamond industry in the Lundas.** J. Pearce, *African Security Review*, Vol. 13, No. 2, 2004, pp. 51–64.

This article examines the post-civil war diamond operations in two of Angola's diamond-producing provinces, Lunda Norte and Lunda Sul. After reviewing the effects of the country's civil war and the conflict diamonds issue, the author delves into the current conditions under which diamonds are extracted. The Lunda provinces, which had been a base for the UNITA rebel group during the country's civil war, now have three types of mining operations: *garimpo*, or "informal" hand digging; dredging, which employs machinery to extract and process diamond-bearing gravel from riverbeds; and formal mining by large companies.

According to Pearce, the *garimpeiros* who work the alluvial diamond deposits are now threatened by Angolan Armed Forces (FAA) seeking to expel them from all diamond-producing areas, particularly those areas of interest to the larger commercial concerns. Reports of brutality at the hands of soldiers are cited. Dredging operations are often carried out by foreign nationals, many from the neighboring Democratic Republic of the Congo, in league with FAA generals. In the formal sector, several large mining operations, particularly at Catoca, have been established, although locals have expressed anger at the mining companies and the Angolan government for policies which, they claim, favor foreign workers.

The author reports that there remains little meaningful employment in the two provinces, and most people still live by subsistence farming. Police and army officials extort funds, not just from diamond diggers, but also from health workers and traders. As a result, many of the provinces' inhabitants remain little better off than they were before and during the civil war. RS

**Tackling conflict diamonds: The Kimberley Process Certification Scheme.** C. Wright, *International Peacekeeping*, Vol. 11, No. 4, 2004, pp. 697–708.

The Kimberley Process Certification Scheme for rough diamonds is the first attempt by the international community to control illegal exploitation of natural resources. It is also the first agreement adopted with an equal partnership between governments, industry, and civil society groups.

The Kimberley Process (KP) was ratified by 54 governments, representatives of the diamond industry, and civil society groups in November 2002. It was put into effect in February 2003. Since then, several challenges to the process have arisen. In July 2003, 18 participating nations were asked to leave until they had adopted proper legislation and internal controls to meet the minimum standards for implementation. Six of these nations have subsequently rejoined. And, in early 2004, discrepancies between official diamond production in the Republic of the Congo and the actual diamond exports coming from that nation caused the KP chairman to withdraw its certification.

The Kimberley Process will receive a full review in 2006. Although the original reason for its adoption—to stop the trade in conflict diamonds—is less relevant because the civil wars have ended, there is an argument for retaining the system because of the potential for terrorists and criminals to launder or transport funds by diamond sales through illicit channels. RS

**Traditional gemstone cutting technology of Kongu region of Tamil Nadu.** K. Rajan and N. Athiyaman, *Indian Journal of History of Science*, Vol. 39, No. 4, 2004, pp. 385–414.

The authors trace the long history of gem extraction and cutting in India's southern province of Tamil Nadu. The Kongu region was, and remains, the source for many gem varieties including beryl, corundum, quartz, and feldspar. Accounts of artisans working gems in the area date back to the 3rd century BC, and Pliny, in the 1st century AD, noted that the best beryls, of a "sea-green" color, mostly came from India.

The authors then discuss the villages of the region and describe in detail the techniques and equipment still employed today by traditional cutters in fashioning faceted stones and beads in those areas. RS