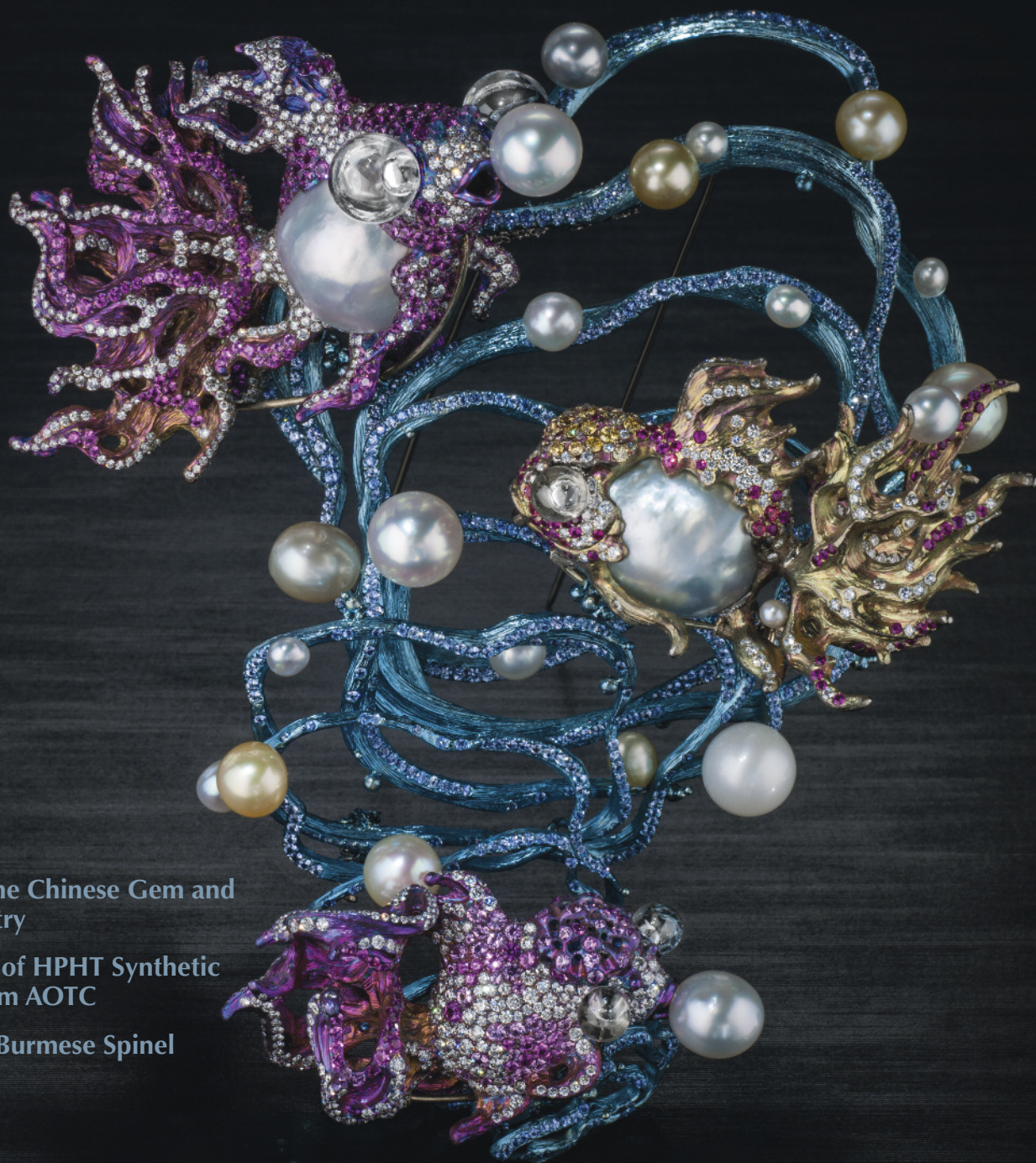


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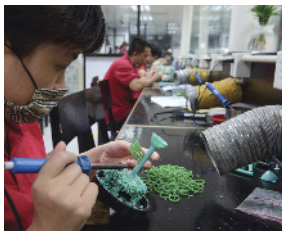
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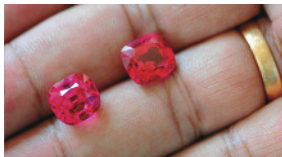
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About the Cover

The lead article in this issue examines China's emergence as one of the gem and jewelry industry's most important manufacturing centers and consumer markets. "Harmony," a brooch designed by Wallace Chan of Hong Kong, epitomizes the bold innovation that has fueled China's dramatic growth. Set in titanium and white gold, the piece includes pink and blue sapphires, colorless and orange diamonds, rubies, red spinels, citrine, and opal. Photo by Robert Weldon, courtesy of Wallace Chan.

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Eighty Years and Still Going Strong



It is truly a privilege to be at the helm of *Gems & Gemology* in the journal's 80th year, following in the illustrious footsteps of Robert M. Shipley, Richard Liddicoat, and Alice Keller. We start 2014 with renewed anticipation and the strongest intention to build on the many notable innovations that shaped *G&G* in previous years. This year, we will continue to foster collaboration with researchers working in related fields at other institutions, while actively producing dynamic media content for the GIA website that complements and adds value to our printed journal.

This issue's lead article focuses on the Chinese gem and jewelry industry. This paper lays the foundation for a series of articles that will explore specific aspects of China's powerhouse industry, including diamond and colored stone cutting, jewelry manufac-

ture, design, and jewelry retail, as well as uniquely Chinese industry sectors like jade carving. The paper is a partnership between Chinese authors Zhili Qiu, Mu Li, and Qingyuan Yu, and *G&G*'s own Tao Hsu and Andrew Lucas. As demand for gem and jewelry products surges in China and impacts consumption patterns elsewhere, this is a very timely topic for our journal to investigate. We will also offer a Mandarin translation of this article with the Spring 2014 issue online at www.gia.edu/gems-gemology.

We start 2014 with renewed anticipation and the strongest intention to build on the many notable innovations that shaped G&G in previous years.

Our second article is a study of near-colorless synthetic diamonds grown using high-pressure and high-temperature (HPHT) by the AOTC Group of the Netherlands. AOTC is the dominant near-colorless HPHT synthetic diamond producer targeting the gem trade. Lead author Ulrika D'Haenens-Johansson, a research scientist at GIA's New York laboratory, investigates the gemological and spectroscopic properties of a suite of 52 colorless to light-colored synthetic diamonds. This important paper illustrates the recent strides made in growth technology and quality.

We are also delighted to present *G&G*'s second field report. Titled "Hunting for 'Jedi' Spinel in Mogok," it details GIA field gemologist Vincent Pardieu's decade-long quest for bright "neon" red spinel in Myanmar's fabled "Valley of Rubies."

In our fourth and final article, we offer a fascinating look at a baroque South Sea cultured pearl from Indonesia that is far larger than the norm for specimens of this type. Ms. Laura Otter and her co-authors use high-resolution computerized microtomography to study the cultured pearl's interior.

In addition to our regular Lab Notes and Gem News International sections, we bring you in-depth coverage of the February 2014 Tucson gem and mineral shows. And don't forget to take the *G&G* Challenge, our annual multiple-choice quiz.

We hope you enjoy the Spring 2014 edition!

A handwritten signature in black ink, appearing to read "Duncan Pay". The signature is fluid and cursive.

Duncan Pay | Editor-in-Chief | dpay@gia.edu

EXPLORING THE CHINESE GEM AND JEWELRY INDUSTRY

Tao Hsu, Andrew Lucas, Zhili Qiu, Mu Li, and Qingyuan Yu

In the wake of its phenomenal economic growth since 1978, China has captured the attention of the global gem and jewelry industry. Already a global hub for jewelry manufacturing, it is now a rapidly growing consumer market. While rising costs of labor in China have created challenges for the manufacturing sector, this has led to greater domestic consumption of luxury products, including jewelry. The highest growth potential lies in the inland urban centers, as Chinese citizens continue a massive migration from rural areas to the cities. Chinese consumers are becoming more knowledgeable about gemstones and jewelry and more astute in their purchases. They have a keen sense of both value and brand trust, and they have become more open to contemporary and Western designs and materials. At the same time, technological advances in manufacturing are leading to higher quality standards and lower labor costs, allowing China to meet the increasing demands of the global and domestic markets. Although the recent global economic crisis has affected domestic sales, the Chinese gem and jewelry industry shows great potential for growth.

The West's fascination with China as an economic powerhouse is equaled by the tremendous opportunities found there. The title of a 2004 *New York Times* article, "The Chinese Century," summed up the widespread sentiment that China will become the world's leading economic power and most influential country early in this century (Fishman, 2004). The same holds true for the gem and jewelry industry: For years a global manufacturing hub, China is emerging as the strongest consumer market for luxury products such as jewelry.

Chinese consumers are now synonymous with luxury products, and this is true with gemstones and jewelry. The Chinese market is the new focus for luxury and glamour for many types of jewelry (figure 1). Although the explosive growth of the last three decades is predicted to slow, domestic consumption and discretionary spending is expected to rise. These trends, along with rapid urbanization, a burgeoning middle class, and a younger generation of sophisticated shoppers, signals exciting opportunities for China and the global gem and jewelry industry. This

requires China to address new challenges, such as sourcing enough gemstones to satisfy import and export demand (figure 2).

ECONOMIC OVERVIEW

In 2010, China overtook Japan to become the world's second-largest economy after the United States (table 1). Overall, China's annual growth rate has averaged

TABLE 1. GDP by country, 2012.

Ranking	Economy	Trillion US\$
1	United States	15.684
2	China	8.227
3	Japan	5.959
4	Germany	3.399
5	France	2.612
6	United Kingdom	2.435
7	Brazil	2.252
8	Russian Federation	2.014
9	Italy	2.013
10	India	1.841

Adapted from the World Bank (2013).

See end of article for About the Authors and Acknowledgments.

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Figure 1. Actress Ning Sun models high-end jewelry from Enzo, a Chinese retailer founded in Hong Kong and a true mine-to-market colored gemstone brand. Photo by Ouyang from China Gems magazine; courtesy of Enzo.

around 10% over the last 30 years (Barnett, 2013). According to China's National Bureau of Statistics, the gross domestic product (GDP) growth for the first half of 2013 was US\$4 trillion, a year-on-year increase of 7.6%. Bloomberg senior economist Michael McDonough correctly predicted that the government would tolerate much slower growth in the second half of 2013, as its strategy shifts to more sustainable long-term growth (Zheng, 2013).

A 7.6% predicted growth may seem low compared to the years of double-digit growth over the past three decades, but it is still quite enviable when compared to growth rates in the U.S., Europe, and

Figure 2. China's consumption of gemstones, both for export and the domestic market, has led to supply shortages and intense competition at mining sources and markets worldwide. Photo by Andrew Lucas.



Japan. The predicted growth rate is certainly very respectable for the world's second-largest economy, with a GDP over \$8 trillion (table 2). Some analysts predict that China will overtake the U.S. as the world's leading economy sometime between 2020 and 2030 (Shamim, 2010), while the International Monetary Fund (IMF) has predicted this will happen before 2020. The timeframe is ultimately dependent on the future growth rate, which is predicted to slow.

Manufacturing. China became the world's largest manufacturing economy (figure 3) in 2010 and in 2012 widened its lead over the U.S. with \$2.9 trillion

Figure 3. China is the world's leading manufacturer overall, as well as the largest producer of jewelry. At this state-of-the-art factory in Guangdong province, workers create a wide range of jewelry. Photo by Eric Welch; courtesy of Chow Tai Fook.



TABLE 2. Economic growth of China, 1979–2012.

Year	GDP (trillion US\$)	GDP increase (%)	GDP per capita (yuan)	Discretionary income per capita (yuan)
1979	0.1766	7.6	419	387
1980	0.1896	7.8	463	477
1981	0.1941	5.2	492	491
1982	0.2032	9.1	528	526
1983	0.2284	10.9	583	564
1984	0.2574	15.2	695	651
1985	0.3067	13.5	858	739
1986	0.2978	8.8	963	899
1987	0.2704	11.6	1,112	1,002
1988	0.3095	11.3	1,366	1,181
1989	0.344	4.1	1,519	1,373
1990	0.3569	3.8	1,644	1,510
1991	0.3795	9.2	1,893	1,700
1992	0.4227	14.2	2,311	2,026
1993	0.4405	14	2,998	2,577
1994	0.5592	13.1	4,044	3,496
1995	0.728	10.9	5,046	4,283
1996	0.856	10	5,846	4,838
1997	0.9526	9.3	6,420	5,160
1998	1.0195	7.8	6,796	5,425
1999	1.0833	7.6	7,159	5,854
2000	1.1985	8.4	7,858	6,280
2001	1.3248	8.3	8,622	6,860
2002	1.4538	9.1	9,398	7,702
2003	1.641	10	10,542	8,472
2004	1.9316	10.1	12,336	9,421
2005	2.2569	11.3	14,185	10,493
2006	2.713	12.7	16,500	11,759
2007	3.4941	14.2	20,169	13,786
2008	4.5218	9.6	23,708	15,781
2009	4.9913	9.2	25,604	17,175
2010	5.9305	10.4	29,748	19,109
2011	7.3219	9.2	35,083	21,810
2012	8.2271	7.8	38,354	24,565

Data compiled from World Bank (2013) and Gemmological Association of China (2013).

in manufactured goods annually, compared to \$2.43 trillion from the U.S. (Sims, 2013). A major factor behind this has been China's surge in domestic consumption (Chen, 2013).

Urban Centers. Chinese cities are generally divided into four tiers. First-tier cities (figure 4) are the most developed and cosmopolitan urban centers; these include Shanghai, Beijing, Shenzhen, and Guangzhou. The other tiers represent cities with less wealth, lower wages, less discretionary income, less infrastructure, fewer amenities, and fewer resources. Unofficially, there are 59 cities in the second tier, 92 in the third, and 105 in the fourth (Schuster, 2012).

Figure 4. First-tier cities like Guangzhou have been the driving force behind China's economic growth. The television tower next to the Pearl River is a symbol of Guangzhou's wealth. Photo by Eric Welch.



Second-tier cities are rapidly developing into commercial centers, and this is reshaping the country's commercial, industrial, and regulatory landscape (Schuster, 2012). With rising costs of labor and land in first-tier cities, manufacturing has moved into second-tier cities and continued into the lower tiers. Government reforms have helped fuel this development. As jobs are created and more resources are allocated into these emerging cities, consumer wages increase, discretionary income rises, and greater discretionary spending occurs. A sizeable portion of this discretionary spending goes to jewelry. Major retailers such as Chow Tai Fook and Chow Sang Sang have recognized the potential of these lower-tier cities for years, aggressively moving manufacturing efforts into these areas.

Special Administrative Regions. Hong Kong and Macau are the only Special Administrative Regions (SARs) of the People's Republic of China. Hong Kong was formerly a British colony, while Macau was a Portuguese colony. They were transferred to China in

In Brief

- In addition to being the world's largest manufacturing economy, China is experiencing a dramatic rise in consumption.
- With its rapid urbanization, a growing middle class, and a young generation of sophisticated luxury shoppers, China could soon become the world's largest jewelry market.
- Business-friendly tax reforms, the establishment of a diamond exchange, and the rise of professional training and lab grading standards have made China's jewelry industry more competitive globally.

1997 and 1999, respectively, under the "one China, two systems" policy. By virtue of their SAR status, Hong Kong and Macau enjoy a high degree of autonomy. While economic studies frequently separate China and Hong Kong, it is important to consider them as one country. The business relationship between the two was established before the change in sovereignty in 1997, especially after the significant economic reforms China instituted in the late 1970s. Many Hong Kong-based businesses set up facilities in mainland China, some right across the border in Shenzhen, to capitalize on less-expensive labor (figure 5).

The advantage of combining low-cost labor and free trade was heightened by the formation of special



Figure 5. Hong Kong-based businesses have helped turn the Guangdong province into a major global manufacturing center. This jewelry factory uses modern manufacturing techniques such as wax models and casting. Photo by Eric Welch; courtesy of Chow Tai Fook.

economic zones (SEZs) in mainland China shortly after the country opened up for trade in 1978. This move fostered free market activity and flexible economic policies, especially for manufacturing and export. The province of Guangdong, including Shenzhen and Panyu, has important SEZs for the diamond, gemstone, and jewelry industries. Many of the products manufactured in these zones are exported to the rest of the world through Hong Kong. Another major economic turning point was China's 2001 acceptance into the World Trade Organization, which removed trade barriers and created a larger market for Chinese goods.

Five-Year Plan. Since 1953, the government has issued a series of five-year plans outlining economic and social strategies. China is currently in its twelfth five-year plan, from 2011 to 2015. The 2011–2015 plan relies less on exports and more on domestic consumer spending to fuel growth. This most recent initiative emphasizes slower but more sustainable growth, and greater reliance on the domestic market. The current five-year plan (see KPMG China, 2011) outlined several key strategies that will influence the nation's economy, including:

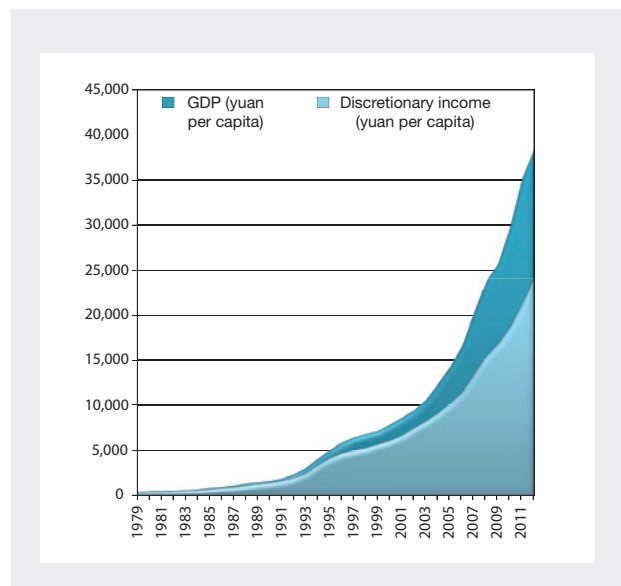
- *Higher-quality growth:* GDP growth goals have been reduced to around 7%, with emphasis on curing problems related to earlier rapid growth, such as environmental issues, resource depletion, and excessive energy use.
- *Inclusive growth:* More equality in growth opportunities is needed to close the wealth gap among individuals and between geographic locations.

- *Development of lower-tier cities and the western regions:* Shifting the emphasis from first-tier cities, primarily in coastal areas, to the less-developed cities and inland western regions has been successful.
- *Transition from an export-driven economy to a domestic market economy:* The current plan reinforces the need to move from reliance on exports for growth to an emphasis on further expanding the Chinese consumer market.
- *Increasing urbanization from 47.6% to 61.6%:* Much of this increase will consist of migration from rural areas to the lower-tier cities.

Discretionary Income. Between 2000 and 2011, approximately 230 million people moved to Chinese cities, in what some have considered the greatest urbanization in history (Rare Investment, 2013). The average disposable income of urban residents was expected to rise 13% annually between 2012 and 2047. According to China's National Bureau of Statistics, the consumption of discretionary goods is expected to grow at a compounded annual rate of 13% between 2010 and 2020 (Barton et al, 2013). The growth rate of discretionary income has been consistently below the GDP growth rate (figure 6).

According to China's National Bureau of Statistics, the gain in household disposable income has

Figure 6. In China, discretionary income has lagged behind GDP. Data from the World Bank and Chinese Jewelry Industry Year Book.



been most prominent among the highest earners, followed by the high-income and upper-middle-class segments, registering compound annual growth rates of 14.5%, 12.8%, and 12.1%, respectively. Members of these classes are the biggest spenders on luxury goods and often have a voracious appetite for the finer things (Fung Business Intelligence Centre, 2013). It is clear that the percentage of discretionary income for higher-income groups has been consistently rising at a faster rate.

Demographics. The key to future growth in China is domestic consumption. The creation of a vast middle class has fueled the rapidly increasing consumption of goods and services. China's middle class is projected to expand from approximately 225 million in 2012 to 330 million by 2025 (Schuster, 2012). Percentagewise, the most dramatic increase of the middle class is expected to occur in the second- and third-tier cities farther inland (Barton et al., 2013).

China's new middle class can also be segregated by age. The average age of individuals with net worth of more than 10 million yuan is 39. Among those with net worth above 100 million yuan, the average age is 41 (Fung Business Intelligence Centre, 2013). China's Generation 2 (G2) consists of some 200 million youths in their teens and early twenties born since the mid-1980s. This demographic represents about 15% of urban consumers (Barton et al., 2013). By 2022, the G2 segment is expected to be three times larger than the U.S. baby-boomer population, and should make up 35% of the domestic consumer market (Barton et al., 2013). Members of this younger generation have a more Western outlook toward consumption. They are confident of their own financial prospects, loyal to brands, willing to try new products, and comfortable shopping on the Internet (figure 7).

The increase in China's middle-class population will inevitably lead to greater domestic consumption. In 2002, 40% of China's still relatively small middle class lived in four cities: Beijing, Shanghai, Guangzhou, and Shenzhen. By 2022, that percentage is expected to drop to 16% due to the faster middle-class growth of cities in the north and west, especially third-tier cities (Barton et al., 2013). When the predicted increase in the upper middle class is charted alongside the projected increase in private consumption, the importance of middle-class purchasing power becomes obvious (figure 8).

According to the global consulting firm McKinsey & Co., and as shown in figure 9, the most important population sector for domestic consumption is the

YOUNG URBAN CHINESE CONSUMERS' WESTERN APPROACH TO SHOPPING

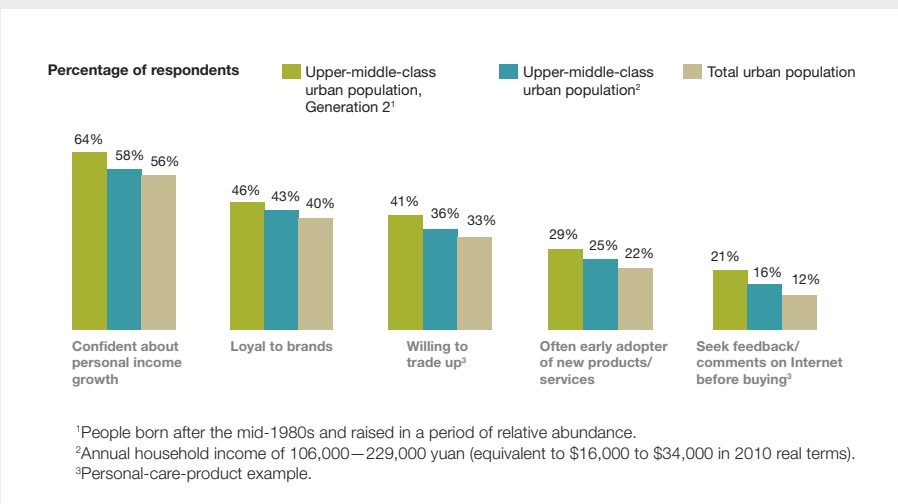


Figure 7. So-called Generation 2 shoppers in their teens and early twenties are an important new class of consumers in China. Their attitudes toward shopping, reflected in this survey of 10,000 Chinese consumers, may alter the way products are marketed and sold. Adapted from Barton et al. (2013), courtesy of McKinsey & Company.

upper middle class (Barton, 2013). The report defines upper middle class as Chinese citizens with an annual income of 60,000 to 106,000 yuan. The same study estimates that by 2022, the upper middle class will account for 56% of urban household consumption. Like their affluent and ultra-wealthy counterparts, upper-middle-class consumers are contributing to the growth of the luxury products market, which has increased 16–20% annually over the last several years (Barton et al., 2013). By 2015, Chinese cus-

tomers will account for over one-third of global spending on jewelry and other luxury items, both in their domestic market and outside China.

The upper middle class are the most Westernized of all Chinese consumers. They show a willingness to try new products, and tend to regard expensive products as intrinsically superior. China's growing middle class also regards discretionary spending on luxury products as an essential element of social status.

Another demographic aspect to Chinese con-

CONSUMER SENTIMENT IN COASTAL VS. INLAND CITIES

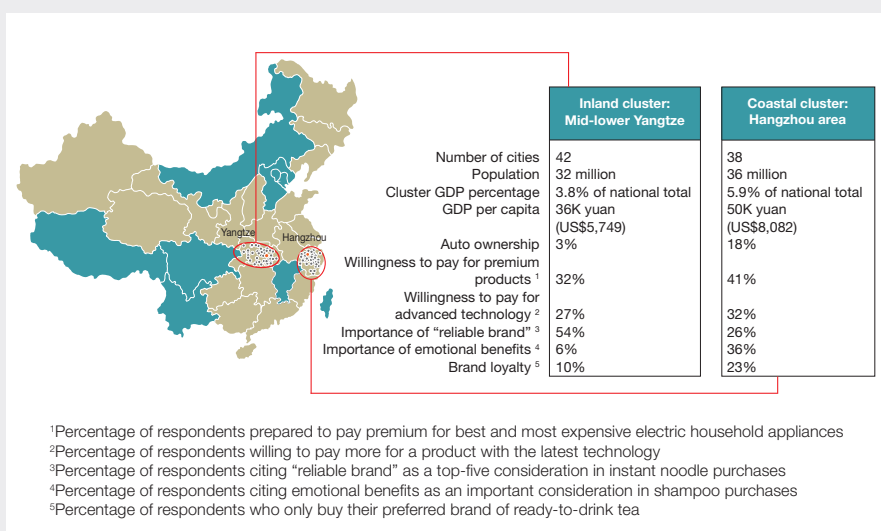
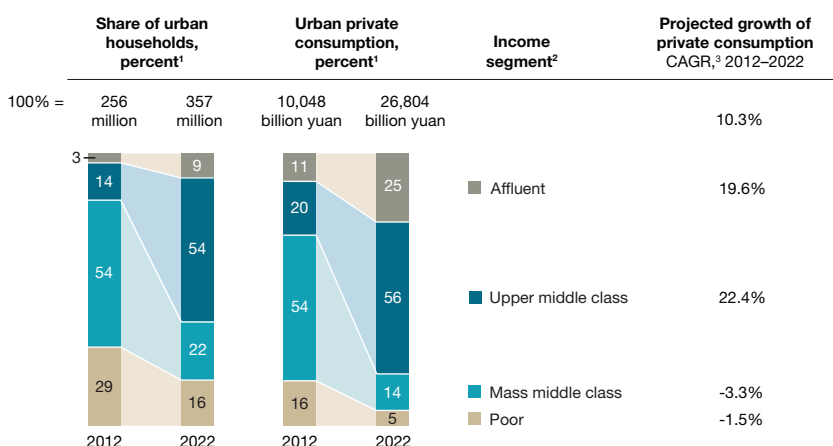


Figure 8. Comparing the inland cities along the middle and lower Yangtze River with the coastal cities, differences in consumer attitudes become evident. Adapted from Atsmon et al. (2012), courtesy of McKinsey & Company.

CHINA'S CHANGING CLASS IDENTITIES



¹Figures may not total 100 percent, because of rounding; data for 2022 are projected.
²Defined by annual disposable income per urban household, in 2010 real terms; affluent >229,000 yuan (equivalent to > \$34,000); upper middle class, 106,000–229,000 yuan (equivalent to \$16,000–\$34,000); mass middle class, 60,000–106,000 yuan (equivalent to \$9,000–\$16,000); poor <60,000 yuan (equivalent to <\$9,000).
³Compound annual growth rate.

Figure 9. The magnitude of China's middle-class growth is transforming the nation by fueling domestic consumption and growth. Adapted from Barton et al. (2013); courtesy of McKinsey & Company.

sumption is the increasing contribution by women to household income. By 2009, women provided 50% of household income (Shaun Rein, pers. comm., 2013), while three-quarters of Chinese women say they control the family finances (Georgette Tan, pers. comm., 2013).

Domestic Consumption. China market analysts predict a shift in the percentage of income used for investment versus consumption (figure 10). In the period from 2000 to 2010, investment comprised 53% of GDP growth, while the rate of private consumption was 27%. These percentages are expected to change dramatically between 2020 and 2030, with 34% of money invested and 51% used for private consumption (Woetzel et al., 2012).

The government expects wages to at least keep pace with, if not surpass, GDP growth. In the first half of 2012, four-fifths of China's administrative districts raised the minimum wage by 19.7% (Woetzel et al., 2012). While rising labor costs create challenges for global competitiveness in manufacturing, the direction is clear, and the growth of Chinese domestic buying power and consumerism is almost certain.

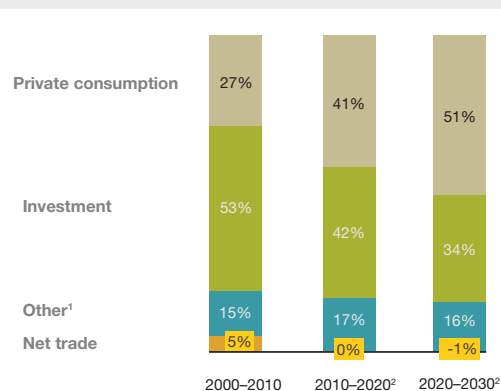
A 2011 survey by McKinsey (Atsmon et al., 2011) revealed several illuminating facts:

- Chinese consumers are often quick to adopt new and unfamiliar products.
- Brand awareness is rising, but not brand loyalty. In China, brands must earn trust. The study

found that Chinese consumers are not blindly brand loyal and are willing to change brands if another earns their trust—more so than in the West. Most Chinese consumers choose from several favorite brands.

Figure 10. Private consumption, the leading contributor to China's economic growth, is expected to overtake investment as the main percentage of Chinese GDP growth. Adapted from Woetzel et al. (2012), courtesy of McKinsey & Company.

CHANGES IN CONSUMPTION VS. INVESTMENT, REAL GDP PERCENTAGES



¹Includes government consumption and inventory.
²2010-2030 data are estimated.

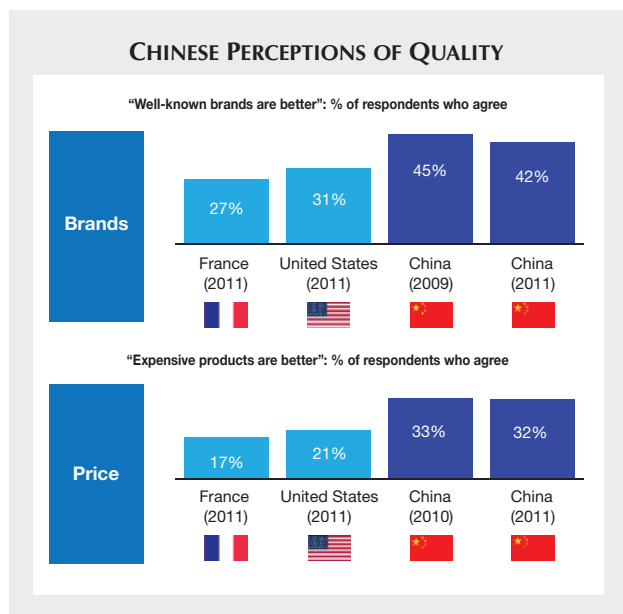


Figure 11. Many Chinese consumers trust the quality of well-known, higher-priced brands. Adapted from Atsmon et al. (2011); courtesy of McKinsey & Company.

- Price also exerts a strong influence (figure 11). Chinese shoppers do not necessarily buy lower-priced items, but they do consider the value for the price.
- The popularity of social media is growing at an amazing rate. By mid-2011, 195 million Chinese people used Sina Weibo, the microblogging equivalent of Twitter. That was triple the number from just six months earlier. The instant messaging tool WeChat (also known as Weixin in Chinese) launched in early 2010 and is growing even faster. CNN reported that WeChat registered 100 million users in its first 15 months and had 271.9 million active daily users in September 2013 (Skuse, 2014). Now people can even buy and sell goods on WeChat, similar to eBay.
- Emotional considerations are important in brand choice and purchases among higher-income consumers (though still below U.S. levels) during 2011, and this trend is expected to continue to rise.
- Despite the economic challenges faced in 2011, Chinese consumers are becoming more confident about their economic prospects.

The same McKinsey survey provided useful suggestions for companies wanting to capitalize on growth and opportunity in China in the future.

- *Prioritize growth opportunities.* While many companies focus on first-tier cities, approximately 60% of consumer goods in urban China are purchased in lower-tier cities.
- *Tailor marketing strategies to capture growth opportunities.* Regional preferences and differences in disposable income dictate that a China-wide strategy will not work as well as one that is optimized for different regions.
- *Focus on perceived value, not price.* Chinese consumers seem particularly sensitive to price. Yet low prices are often associated with low quality, and getting good value for the money is the key consideration.
- *Build mass appeal and meet the needs of specific consumer groups.* As Chinese consumers become more discerning, products must be targeted to certain types of shoppers. Companies that market a variety of product lines to specific consumer groups may be well poised in the coming years.
- *Modernize marketing tools.* Though expensive, traditional mass-media advertising, such as television commercials, are highly effective in China. Internet commerce and social media gained acceptance more slowly in China than in the West, but the last few years have seen an extraordinary rise in online retail sales and in small businesses using social media. More attention to Internet marketing has the potential to facilitate greater growth.

Import and Export. China ranks 96th out of 189 countries worldwide for ease of doing business (World Bank, 2013); in comparison, the U.S. is 4th and India 134th. China's standing does not tell the whole story, however. Many businesses, including foreign ones, are opening up in China because of the tremendous growth potential there. Additionally, Hong Kong, which has its own business regulations as a Special Administrative Region, ranks second in the World Bank's report, and much of China's trading is done through this free-trade zone. As previously noted, many companies originally based in Hong Kong have moved into mainland China, in part because of the low-cost manufacturing and export, but also to reach the domestic consumer market.

China is the world's second-largest exporter, just behind the European Union (Central Intelligence Agency, 2013). China is also the third-largest importer of goods, trailing only the European Union and

the United States. These statistics demonstrate China's important role in the global economy.

Luxury Products. Greater China, including Hong Kong and Macau, is the world's second-largest consumer of luxury products. Chinese consumers purchase half of all luxury products in Asia and one-third of those in Europe (Bain & Company, 2012). The rising rate of luxury purchases in the U.S. is partly due to Chinese tourism. Predictions indicate that the Chinese market will mature but continue to grow both at home and globally, as Chinese tourists travel abroad to shopping destinations such as Paris, New York, and Hawaii.

China's slowdown in luxury spending growth in 2012 was partly due to increased luxury shopping overseas by Chinese tourists, along with the economic recovery. Chinese trade members interviewed for this article also cited new regulations, brought on by negative publicity, that have discouraged government officials from flaunting lavish luxury gifts.

Meanwhile, Chinese consumers are becoming more sophisticated in their shopping habits, moving away from purchasing only brands with well-known logos and toward quality and value in luxury products (Bain & Company, 2012). Even though status symbols remain an important part of the Chinese luxury market, brands that can also demonstrate value are more likely to thrive. Shoppers in first- and second-tier cities are not purchasing goods based on conspicuous branding alone. They are also looking for quality, value, uniqueness, and a low-key statement. Consumers in third- and fourth-tier cities, who tend to be less sophisticated in their shopping, still seek brands with conspicuous logos (figure 12). Yet the cultural heritage of a brand is becoming a more important consideration than just the logo (Fung Business Intelligence Centre, 2013).

Chinese luxury brand shoppers are shifting from predominantly older businessmen to younger shoppers and women (Bain & Company, 2012). Sixty percent of Chinese luxury consumers are between 20 and 39 years of age, compared to only 38% in Western Europe (Fung Business Intelligence Centre, 2013). Only 7% of Chinese luxury consumers are over the age of 60, as opposed to 21% in Western Europe (Hurun, 2013). Notably, 40% of the 102 million Chinese people with personal wealth above 10 million yuan are women. Affluent women's spending on luxury goods increased from 25% in 2010 to 46% in 2012 (Lui et al., 2012).

CHINESE ATTITUDES TOWARD LUXURY LOGOS

Do you plan to purchase more luxury goods with conspicuous logos?

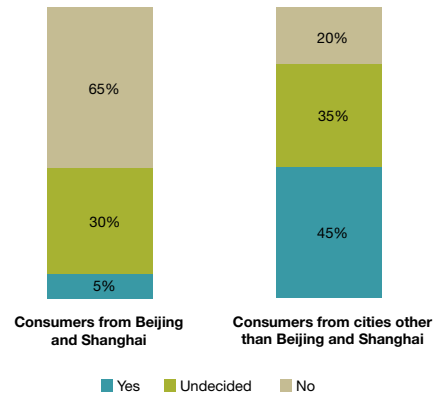


Figure 12. Consumers in third- and fourth-tier Chinese cities are much more likely to buy luxury products with conspicuous logos than shoppers in first- and second-tier cities. Adapted from Bain & Company (2012).

Internet Retail. E-commerce in China has grown tremendously in the last few years, including sales of clothing, electronics, and gems and jewelry. Individuals in third- and fourth-tier cities actually spend a higher percentage of disposable income shopping online than first- and second-tier residents (Dobbs et al., 2013). Jewelry companies like Zbird, a pioneer in China's Internet diamond jewelry sales, have spent years building customer confidence in online purchases. Several Western luxury jewelry retailers, including Cartier, Bulgari, and Tiffany, rank among the most followed luxury brands on social media (figure 13).

China's phenomenal growth in e-commerce was demonstrated in late 2013, on the unofficial holiday known as Singles' Day. The event falls on November 11, with the calendar date of 11/11 representing unmarried people. For years, Singles' Day was a social occasion for China's large bachelor population. In 2008, the Chinese e-commerce giant Alibaba began promoting Singles' Day as an e-commerce event. (Two of Alibaba's sites, Taobao and Tmall, have a transaction volume larger than that of Amazon and eBay combined.) Most other Chinese e-commerce sites quickly followed suit, offering deals on all types of consumer goods. All told, Singles' Day 2013 brought in more than US\$5.75 billion, making it the biggest one-day e-commerce event of all time, well

**FOLLOWERS OF SELECTED LUXURY BRANDS ON SINA WEIBO
(AS OF MARCH 18, 2013)**

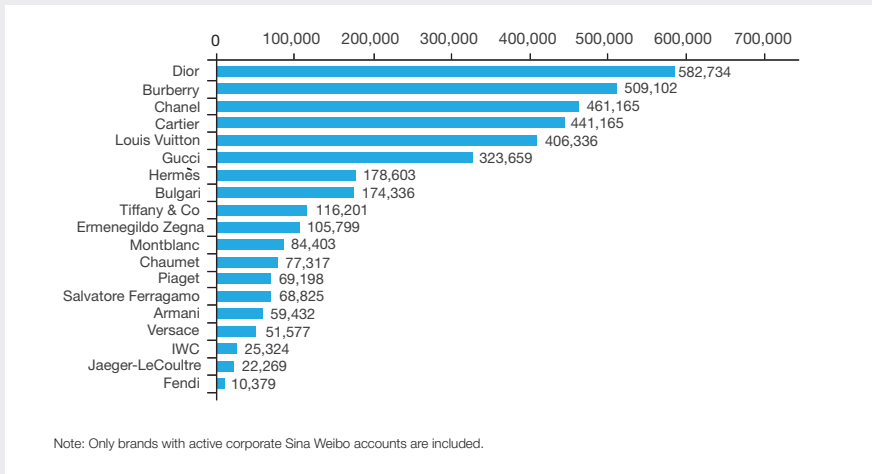


Figure 13. Several Western jewelry brands are among the luxury brands most followed on Weibo. Adapted from Fung Business Intelligence Centre (2013).

surpassing Cyber Monday 2012 in the United States (Wang and Pfanner, 2013).

Alibaba alone reported 402 million unique visitors to its sites on Singles' Day 2013, and prepared 152 million parcels for shipping. The gem and jewelry industry played a role in this success. In one instance, a woman from Zhejiang province purchased a 13.33 ct diamond costing \$3.37 million (Wang and Pfanner, 2013).

THE CHINESE GEM AND JEWELRY INDUSTRY

Historical Perspective. Jewelry has a well-established history in China, where gold and silver have been used for decorative purposes for at least 3,000 years. Based on archaeological evidence, the Chinese began using jade even earlier, during the New Stone Age (Zhang, 2006).

With the development of manufacturing techniques, precious metal decoration evolved from the simple gold sheet and leaves discovered in tombs dating from the Shang dynasty (circa 1700–1100 BC) to the delicate jewelries embedded with local and Western elements in the Han and Tang dynasties (265–907). Precious metal art reached its peak during the Ming and Qing dynasties (1368–1912), with luxury gold and silver practical wares and jewelries made for the royal families (figure 14) still in existence.

Before jadeite was imported from Burma, early in the Qing dynasty, references to “jade” in Chinese records signified nephrite. Owing to its special color, luster, and structure, nephrite was thought to represent the conservative character of China’s cul-

ture and the spirit of its people. Originally used for tools and sacrificial vessels, jade gradually became the stone of choice for practical wares, jewelry, and carvings.

The Qing emperors’ love of jadeite influenced its prominence. Historically, jadeite has been imported from Burma in two ways: through the boundary between the two countries in southwestern China, and through the port at Guangzhou, which became the capital of the jadeite trade. From 1873 to 1878, an average of 200 tons of jadeite was imported yearly

Figure 14. These 24K gold fingernail protectors are replicas of the versions made for the royal family during the Qing dynasty. Photo by Eric Welch; courtesy of Zhaoyi and Bai JingYi.



through Guangzhou (Li, 2013). Today, the famous jadeite manufacturing and trade centers of Guangzhou, Jieyang, Sihui, and Pingzhou are still very active.

The Modern Jewelry Industry. Throughout China's history, small-scale manufacturers, along with royal studios and workshops, dominated the market. Once the emperor commissioned a workshop to manufacture an item, the products were hallmarked and could not be traded by private parties. The strict enforcement of this rule on trading delayed the development of the jewelry industry in China.

The modern Chinese jewelry industry began with the rise of *Yinlou*, private businesses that acted as precious metal manufacturers and dealers, from the end of the Qing Dynasty until the formation of the People's Republic of China in 1949. Most of the *Yinlou* (which translates to "silver mansion" in English) also served as pawn shops. The British victory in the First Opium War (1840–1842) paved the way for the opening of the lucrative Chinese market and society as a whole, which triggered the development of modern industry in China. With access to the breakthroughs of the West's Industrial Revolution (circa 1760–1840), the Chinese started to form modern factories and businesses.

Unlike the workshops and the royal manufacturers that were the norm before the Opium War, the *Yinlou* were backed by private investors and operated on a larger scale. There was even a professional guild to represent all these businesses in their dealings with other industries and the government.

By the end of the Qing dynasty in the early 20th century, many of these businesses had established reputations and become leaders in the industry. In Shanghai, nine respected *Yinlou* formed a jewelry industry association in 1896. Since then, precious metal trading in Shanghai has been self-regulated (Sun and Nie, 2008). Among the original nine companies, Lao Feng Xiang (figure 15) may be the most famous. Formed in 1848, it operated three chain stores in Shanghai until 1949. In 1952, the Communist government bought the stores, and it remains a state-owned business. After numerous ups and downs, Lao Feng Xiang is presently thriving as China's second-largest jewelry retailer after Chow Tai Fook, with over 2,300 retail outlets all over the country.

Other *Yinlou* companies were located along China's east coast. Although nearly all of them disappeared during the Sino-Japanese War (1937–1945)

and the Cultural Revolution, some survived and are trying to revitalize their business in the current jewelry market. *Yinlou* helped set the stage for the modern Chinese industry.

Post-Cultural Revolution. After years of war, followed by the Cultural Revolution from 1966 to 1976, China finally had the opportunity to modernize its economy. When we talk about this new era of the Chinese jewelry industry, these 30 years can be roughly divided into four stages.

Recovery Period (1976–1989). During the Cultural Revolution, a turbulent period when communism was strictly enforced, jewelry and other luxury products were taken off the market. In 1982, the political constraints imposed on the jewelry industry were finally removed. In 1986, the government released 100 tons of gold to the market for jewelry manufacturing. Following this, the jewelry industry became independent again after nearly 30 years of state control (Zhang, 2008).

New jewelry companies and old brands worked to build their businesses, but sales were severely confined by China's underdeveloped economy and lack of discretionary income among its citizens. Statistics show that in 1980 there were only 10 gold jewelry manufacturers in the entire country, employing about 10,000 workers (Zhang, 2008). Most stores at this time only carried fine gold jewelry. Consumers had almost no jewelry knowledge, so most purchased whatever was available, simply as a hedge against in-

Figure 15. Lao Feng Xiang, one of the original *Yinlou* businesses, formed in 1848. This undated photo shows their original Shanghai location. Photo courtesy of Lao Feng Xiang Co., Ltd.



flation. With a limited amount of gold circulating in the market, supply often could not satisfy consumer demand. Retailers were primarily state-owned department stores, and privately owned companies were rare (Qiu et al., 2002).

Dynamic Growth (1990–2000). The Chinese jewelry industry experienced a dramatic upswing in the last decade of the 20th century. In the early 1990s, many state-owned jewelry companies formed. With money to invest in human resources and technology, these businesses started to collaborate with foreign companies and large, state-owned department stores. Some foreign jewelry companies entered the Chinese market for the first time, with De Beers forming its first Chinese diamond promotion center in Shanghai. The four most successful Hong Kong jewelry brands (Chow Tai Fook, Chow Seng Seng, Tse Sui Luen, and Luk Fook) entered the mainland market as well (figure 16). By the end of the 1990s, there were about 20,000 jewelry businesses and three million workers involved in the jewelry industry (Gemmological Association of China, 2013). In 1990, gross jewelry sales were about 2 billion yuan (US\$300 million). By the year 2000, this number climbed to 89 billion yuan (US\$15 billion) (China Economic Net, 2012). The largest growth in the Chinese jewelry industry happened in the 1990s (table 3), and most of today's companies were formed during this decade.

With the presence of De Beers, Chinese consumers began to feel more comfortable purchasing diamonds. Some consumers actually paid too much attention to the quality of diamonds. For instance, some customers purchasing a 10-point diamond would insist on G color and VVS clarity (Qiu et al., 2002). Medium- and low-quality corundum were also imported from global sources and trading centers. Jewelry featuring mounted gemstones found a market, but jewelry clientele still knew little about gems. Platinum made its greatest advance in the 1990s. In 1994, China's platinum consumption comprised only 1% of the world market. In 1998, this figure rose to 23%, with China ranking second in world platinum consumption (Zhang, 2008).

Through the 1990s and into the 21st century, the state-owned department stores were still the main jewelry-selling channel. Some department stores thrived after they start focusing on jewelry sales; Beijing's Cai Shi Kou store is one famous example. Though no longer a department store, from 1989 to 2012 it was ranked Beijing's top gold jewelry seller every year. It now markets its own jewelry brand.



Figure 16. Chow Tai Fook retail stores are now commonplace in China's urban centers. Photo by Eric Welch.

Guo Hua, also in Beijing, is another success story. After following a path similar to Cai Shi Kou's, it is now Beijing's leading platinum jewelry seller.

Steady Growth (2000–2008). In the 21st century, China's domestic jewelry industry entered a steady growth period. In 2001, the country was the world's leading consumer of platinum. In 2007, its gold consumption reached 363 tons (figure 17), second only to India's (Zhang, 2008). As a result of this growth, both the jewelry market and consumers matured. The focus of the industry shifted from quantity to

TABLE 3. Jewelry sales in China, 1990–2012.

Year	Gross sales (billion yuan)	Increase (%)
1990	2	
1993	24.1	1,105
2000	89	269.3
2001	96.5	8.4
2002	105.3	9.1
2005	140	15
2006	160	14.29
2007	160	0
2008	180	12.5
2009	220	22.22
2010	250	13.64
2011	380	40
2012	454	19.2

Data compiled from China Economic Net (2012) and Zhang (2008).



Figure 17. The gold market has seen tremendous growth in China since the 1990s. Photo by Andrew Lucas; courtesy of Bartar Jewellery Co., Ltd.

quality. Companies that could not compete went out of business. By 2000, jewelers realized the importance of branding and started promoting products by emphasizing cultural and historical significance rather than simply lowering prices. Consumers started to pay attention to design rather than just focusing on the value of the materials being used.

A New Start (2008–Present). The 2008 Summer Olympics in Beijing (figure 18) helped shed light on Chinese society, opening the country even more to the rest of the world. Meanwhile, Chinese tourism abroad has increased, the GDP per capita has risen, and more income is being spent on luxury goods.

Figure 18. The 2008 Summer Olympics in Beijing marked another milestone for China's emergence as a global leader. The state-of-the-art Beijing National Stadium, also known as the "Bird's Nest," served as a symbol of these Olympics. Photo © iStockphoto.



While the global economy experienced a severe shock with the recession of 2008–2009, the Chinese jewelry industry slowed only slightly. Trade officials note that with the rise in discretionary income in the early 2000s, jewelry became the third-largest investment purchase, after real estate and automobiles. In 2009, more than 11 million couples got married in China, a number that is expected to rise through 2019 (China Economic Net, 2012). A survey by the Shanghai Diamond Exchange indicated that 8 out of every 10 new couples from first-tier cities such as Beijing, Guangzhou, and Shanghai were willing to purchase diamond wedding rings. The Platinum Guild International (PGI) surveyed eight major Chinese cities and found that 84% of prospective brides desired platinum wedding rings (Wen, 2012). And a recent online survey conducted in Shanghai showed that 50% of new couples spent 15,000–20,000 yuan (US\$2,500–\$3,000) on wedding jewelry (Lin, 2012).

Today's consumers know far more about the products they purchase than ever before. This is partially due to better disclosure from sellers and easy access to product knowledge through different channels, especially online resources. Many diamond consumers already know exactly what they want before they step inside a jewelry store or place an online order. As Chinese jewelry shoppers have become better educated, they have cultivated more of an appreciation for design, including Western and innovative Chinese styles. In 2013, several Chinese designers conveyed to the authors these changes in their customers' buying habits. Rather than thinking only in terms of the value of the materials, Chinese jewelry consumers increasingly think in terms of design, value, and the quality of the piece as a whole. Whereas haute couture was very rare in China only five years ago, nearly every mainstream jewelry company now offers luxury products and services. Some designers focus exclusively on custom haute couture jewelry for high-end clientele.

ECONOMIC FACTORS

For any business in China to prosper, it needs the support of government at all levels. Similarly, the government's fiscal policies can benefit both the individual company and the entire industry. Upon opening the country to trade after 1978, the central government enacted major reforms to catch up with other global economies. Additional reforms, such as anti-corruption measures and environmental protection, are necessary to continue this development.



Figure 19. Establishing the Shanghai Gold Exchange was an instrumental development in opening up China's gold market for investment and jewelry use. Photo courtesy of China Gems magazine.

Tax Reform. Since 1978, China has transformed its tax system several times to adapt to its own rapid economic development. A large-scale transformation of the socialist economy occurred in 1994, with a shift toward free-market policies. Since 2003, China has implemented a series of reforms primarily related to income, property, and export taxes. As of 2012, there were 25 tax categories in China. The central government relies heavily on consumption-based taxes, which are less damaging to individual savings than traditional income taxes (Institute for Research on the Economics of Taxation, 2010).

Legislative power over tax laws in China is highly centralized. Only the state council can create and reform national tax laws or policies. Tax collecting responsibilities belong to the State Administration of Taxation. Local governments can slightly adjust some tax rates under certain circumstances, but in general, the power of local government to add or remove taxes, or change major tax rates, is very limited.

Unlike the U.S., China relies more on consumption taxes than income taxes. Value-added tax (VAT) is a large portion of the taxes that an enterprise or individual pays; this applies to jewelry companies as well. According to the State Administration of Taxation website, there are two basic rates: 13% and 17%. While exporting certain jewelry industry products, such as colored gemstones, to China can be challenging for foreign companies, gold and diamonds have exchanges in China that have clarified and simplified importations.

Gold Exchange. The Shanghai Gold Exchange (SGE), founded by the People's Bank of China in October

2002, is a nonprofit organization that regulates gold transactions domestically (figure 19). It provides facilities and supervision for gold transactions, sets precious metal prices domestically, and connects the Chinese and international markets. The SGE also works with testing institutions to conduct qualification examinations for gold quality standards.

Several events led up to the formation of the Exchange. In 2000, the government developed a five-year economic plan that included an open gold market (Skoyles, 2013a). A year later, the People's Bank of China eliminated its monopoly of the nation's gold market. Shortly thereafter, gold price quotes were released on a weekly basis, allowing for adjustments to the gold spot price to reflect free market prices. This effectively paved the way for the SGE (Skoyles, 2013a). As a result, the price of gold in China is based on the open international market.

In 2011 alone, over one million gold savings accounts were opened at ICBC, China's largest bank, as well as 14.4 million gold futures contracts on the Shanghai Gold Futures Exchange. Jewelry remained China's largest gold demand, with a growth in 2011 of 27.87%, 5.45 times higher than the rate for 2010 (Shanghai Gold Exchange, 2011). Much of this sharp rise was attributed to an increase in personal income and the need for a hedge against inflation; the latter drove investors to buy when prices were rising instead of falling. By 2012, China's total gold consumption reached 832.18 tons (figure 20), and the SGE had become the world's largest physical gold exchange.

Figure 20. China has seen a steady increase in gold consumption. Adapted from Sina Corporation (2013).

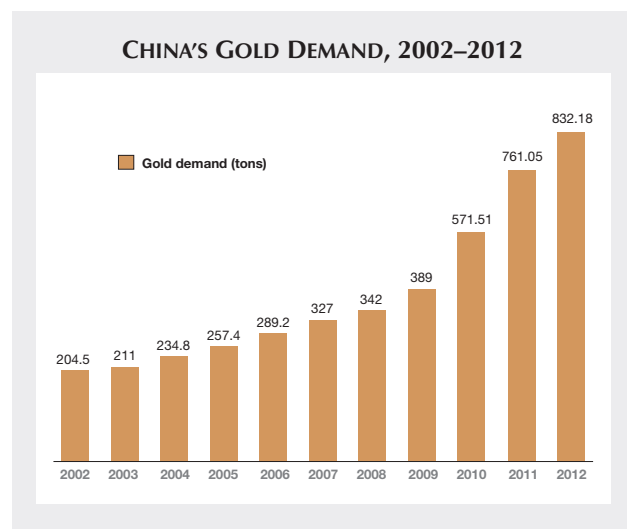




Figure 21. The China Diamond Exchange Center houses the Shanghai Diamond Exchange, one of the world's most important diamond bourses. All legal diamond imports enter China through this building. The exchange is a one-stop shop for all Chinese diamond importation needs. Photo courtesy of China Diamond Exchange Center.

In the first six months of 2013, the SGE supplied 1,098 tons of gold to China for domestic consumption, totaling more than 25% of global supply (Skoyles, 2013a). SGE has 41 warehouses in 34 Chinese cities to facilitate stocking and delivery of gold. Gold is physically delivered to members three days after a deal is completed.

Diamond Exchange. In October 2000, the Shanghai Diamond Exchange (SDE) was established. Housed in the China Diamond Exchange Center (figure 21), the SDE is often referred to by that name. Prior to that, taxation—including tariffs, VAT, and sales tax on diamond imports—was very high, around 35% to 40%. Thanks to the work of the Exchange, diamond taxation policy is now very favorable (table 4). While all goods imported into China are charged a 17% VAT, 13% is refunded for polished diamonds, leaving the net VAT on diamond at 4%. If the rough is pol-

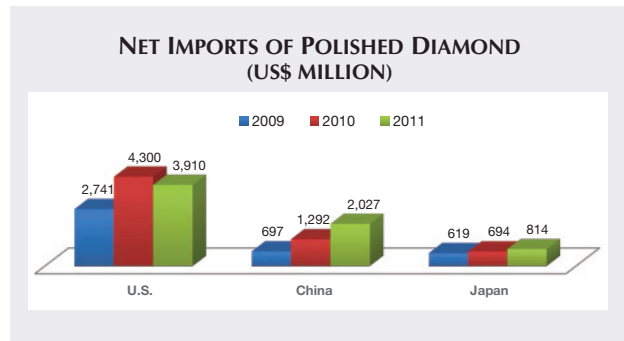


Figure 22. The growth rate of diamond imports into China has far exceeded other major world markets. Adapted from the China Diamond Exchange Center Compendium (2013).

ished in China and then sold in the domestic market, VAT is applied, the same as any polished diamond imported into China. If the rough is polished in China and returned to the country of export, then no VAT is applied. These reforms were instrumental in curbing the smuggling of diamonds into the country to avoid taxation.

The China Diamond Exchange Center is home to a grading and identification lab, diamond dealers, government agencies, and shipping services. It is the central location for all of China's diamond imports and exports. The Diamond Exchange handles all import and export of loose diamonds under normal trade, but not diamond jewelry. The Exchange joined the World Federation of Diamond Bourses in 2004 and hosted the 33rd World Diamond Conference in Shanghai in 2008.

The Chinese diamond industry has benefited greatly from the Diamond Exchange. Before its formation, the official value of diamond imports was about US\$1 million annually. By 2011, diamond import value had reached over US\$5 billion annually, of which around \$2 billion was imported solely into mainland China (figure 22). According to the Diamond Exchange, imports dropped by 10% in 2012

TABLE 4. China's diamond taxation policy.

	Before June 2002	June 2002–June 2006	July 2006–present
Tariff	Rough: 3%; polished: 9%		0%
VAT		17%	Rough: 0%; polished: 4%
Consumption tax		10% at the import stage	5% at the retail stage

Data compiled from China Diamond Exchange Center (2013).

due to worldwide economic conditions, but indications pointed to a higher value for 2013.

The China Diamond Exchange Center is the only legal processing area for diamond import and export. Set up by the central government, its mission is to make trade more convenient by simplifying diamond import and export procedures. According to Chinese law, all imported diamonds must be received at the Exchange to begin the taxation process (figure 23). These imports must be declared and sealed by Chinese customs or else they are considered illegally smuggled. The diamonds are unsealed, inspected, and assessed by an expert at the Exchange before taxation is imposed.

Likewise, imported rough diamonds must be inspected before entering China. Kimberley Process certificates must accompany these diamonds, and a special department in the Exchange is set up for inspecting and registering the certificates. Once the certificates pass inspection, the rough can be sold in the domestic market. After serving as vice chair country of the Kimberley Process for 2013, China became the chair country for 2014, with an officer from China's National Bureau of Quality Inspection assuming the chairmanship.

The China Diamond Exchange Center is a completely open platform that welcomes diamond dealers from all over the world. It has more than 350

members, of which 67% are from Israel, Belgium, the United Kingdom, France, the United States, Japan, Africa, and other overseas locations. There are 114 member diamond companies from mainland China, 62 from Hong Kong, 50 from India, 32 from Israel, and 23 from Belgium; the remaining 69 are from other countries.

Diamond Administration Center of China. The Diamond Administration Center of China (DAC) was established in April 2000. It is authorized by the Ministry of Commerce to supervise the Diamond Exchange. The DAC and other government organizations jointly control everyday diamond imports and exports across the country, as well as trade within the China Diamond Exchange Center.

Functions of the DAC include administration and statistical analysis of national diamond imports and exports, examination and verification that transactions meet the requirements of the Diamond Exchange, and supervision of the Diamond Exchange's operations. The DAC also coordinates with other government officials within the Exchange, approves and oversees the activities of foreign-invested diamond countries within China, participates in the creation of diamond import/export policies, and provides services to the Diamond Exchange and domestic and foreign diamond companies.



Figure 23. Taxes are collected on diamonds once they leave the Exchange to enter the Chinese domestic market. Adapted from the *Diamond Administration of China* (2007).

Colored Stones. Unlike diamonds and gold, which are traded in their own exchange centers with special tax policies, colored stones and colored stone jewelry are taxed at the same rate as other luxury goods. Because China does not have rich colored stone resources, this market depends mainly on imported goods. Tariff, VAT, and consumption tax are collected by the central government, while the local government collects business taxes. The customs tariff of imported colored stones is 8%, and retailers or wholesalers pay an additional 10% business tax. The VAT of mounted colored stone jewelry is an unusually high 17.5%, while consumption tax is 5%. In total, a jewelry retailer or wholesaler pays about 40% on colored stones, driving up prices for these products significantly. For example, a Cartier LOVE bracelet that sold in Hong Kong for 34,855 yuan (US\$6,000) in 2013 cost 47,300 yuan (US\$8,000) in nearby Shenzhen. This difference of about 35.7% is at least partially due to China's high tax rate on colored stone jewelry (Fung Business Intelligence Centre, 2013).

Taxes collected by the central government are related to different industries; thus, it takes longer for changes to occur. There are still some special policies that can help to lower these tax rates. For example, the formation of the Diamond Exchange allowed all diamonds to be traded under special tax rates, which effectively lowered the taxes collected by the central government. A similar organization might help with the colored stone industry. Moreover, reciprocal import-export policies between China and other countries help to lower the tariff, as does the formation of some special trade zones in China. The hardest part to change is the VAT, because China's central government is heavily reliant on this tax. To change it just for one industry is even harder (Qiu, 2013). Local taxes seem to have more flexibility than those collected by the central government, as they are more dependent on the attitude of the local government toward developing its jewelry industry.

LAB STANDARDS

Based on modern gemological knowledge, industry standards were created to standardize the gem and jewelry trade and protect consumers. Over the past 30 years, China formed a series of lab standards based on both Western examples and research by Chinese gemologists.

The three most important are the Jewelry Industry Nomenclature Standard (GB/T 16552-2010), the Gem Identification Standard (GB/T 16553-2010), and the Diamond Grading Standard (GB/T 16554-2010).

These standards apply to all labs across the country. They were first published in 1996, and updated versions were issued in 2010 and applied to lab work effective February 2011 ("2010 edition of the three...", 2011). In addition, there are standards for precious metals.

As the largest jadeite consumer in the world, China has sought a national standard on jadeite grading for years. It is a very difficult process, because jadeite has a wide range of appearances, including transparency, color zoning, and texture. Therefore, every piece is unique and evaluated largely on personal experience using trade jargon. In 2009, the General Administration of Quality Supervision, Inspection and Quarantine and the Standardization Administration published a national jadeite grading standard, GB/T 23885-2009. This standard mainly deals with green jadeite (figure 24), but it can also be applied to transparent, lavender, and red-brown material. The four factors evaluated are color, transparency, texture, and clarity. Gemologists may also comment on the craftsmanship of a particular piece on the certificate. The current standard uses letters to represent different grades while also using the corresponding trade jargon, so that consumers and dealers alike can easily connect the lab report with their goods. The establishment of this standard was supported by both the NGTC lab and high-end jadeite dealers.

China is also the world's largest cultured pearl producer. In 2002, a grading standard (GB/T 18781-

Figure 24. The value of green jadeite has risen tremendously in China, and differences in qualities or grades can make large differences in price. Photo by Eric Welch; courtesy of Zhaoyi.



2002) was published regulating the terminology, grading factors, analysis methods, and product labeling for both saltwater and freshwater cultured pearls.

Some other colored stone varieties have a huge market in China, namely ruby, sapphire, rubellite, and more recently tanzanite. Consumers and gemologists expect more national standards to be issued and applied to identification and evaluation so they will be better guided in purchasing and certifying these gems.

PROFESSIONAL EDUCATION AND TRAINING

In 1980, only 20,000 people throughout China were involved in the jewelry industry. Thirty years later, more than three million are employed in this field. The structure of the jewelry training and education system changed over the same period. The jewelry industry requires workers skilled in mining, manufacturing, sales, and management. At the same time, gemology, design, and engineering experts are also needed for the development of this industry. Compared to many other countries, China has a very specialized jewelry training and education system (figure 25). There are two main components of this system.

Professional Training. Before any modern training organizations formed in China, knowledge was passed from master to apprentice. This system, which existed for thousands of years until the very recent re-opening of the country, focused on one-on-one training. It was not efficient in training a large pool of workers. Modern certificate training programs, first established in the West, have been successful in this regard. China imported these foreign programs.

In 1989, the China University of Geosciences in Wuhan formed a collaborative teaching center with the Gemmological Association of Great Britain to launch the first FGA program in China's history. Fifteen students were enrolled in that program (Yang, 2013). After that, more foreign gemology and diamond certificate training programs were established in mainland China. For example, the Diamond High Council (HRD) opened an education center in Shanghai in 1993, followed by Gem-A in Wuhan a year later. The Gemological Institute of America taught its first Chinese graduate gemology courses in Beijing in 1998. Altogether, these accredited programs trained about 300 students every year (Yang, 2013).

As more gemologists were trained, China started to develop its own certification programs. Different authorities, including universities, national gem and jewelry technology centers, and gemological societies,



Figure 25. Gemological training has been critical to ensuring growth in the Chinese jewelry industry. Photo by Eric Welch; courtesy of Chow Tai Fook.

can all issue professional certifications. The China University of Geosciences in Wuhan, for instance, issues a certificate called the GIC; about 4,000 people were enrolled in this program in 2012 (Yang, 2013). The training content in these courses includes gemology, manufacturing, design, sales, and management. Competition between education providers, both foreign and domestic, has led to the development of more specialized training programs. Many local labs offer high-end classes for management-level personnel from jewelry companies, banks, and insurance companies to help them better understand the trade and related investment options. Labs and associations at the national level also collaborate with sales experts from leading jewelry brands to offer sales and management classes for store personnel. Some jewelry advisors even offer one-to-one classes for high-end investors and collectors.

Gemology Certificates and Degree Programs. Another distinguishing feature of the training system in China is its higher-education programs in gemology. Since the mid-1980s, some universities have offered gemology degrees, which are equivalent to an associate's degree in the United States. The Gemmological Institute at the China University of Geosciences in Wuhan, the first of its kind officially registered by the central government, was formed in 1992. In 1998, the Ministry of Education added gemology as a major in the nation's universities (Yang, 2013), allowing students to pursue degrees up to and including doctorates. This

academic major expanded to include jewelry design, jewelry manufacturing, and jewelry business management. In 2009, the Gemmological Institute in Wuhan became the first university to offer a master's-level program in jewelry design (Yang, 2013).

To secure the talent needed to compete in the jewelry industry, many companies provide their employees with special training and higher salaries. The president of the Pingzhou Mazu jadeite company pointed out that many of his jadeite carvers earn salaries of more than one million yuan per year (US\$150,000). The factory leader from one major diamond-cutting factory in Guangdong province also noted that salaries there have increased by about 15% annually for several years.

JEWELRY MANUFACTURING

China, the world's foremost manufacturing center, is arguably the leading jewelry maker. Most of these operations are based in Guangdong province. Over 2,000 companies are located in Shenzhen, with an annual output of US\$8 billion. This is estimated at over 70% of China's actual jewelry production ("Shenzhen steps up role...", 2012). China is moving from a primarily low-cost manufacturing model to one with a highly skilled workforce and state-of-the-art technology such as laser sawing for diamonds,

Figure 26. Tremendous amounts of colored gemstone rough are required to fill the needs of the Chinese gemstone cutting and jewelry manufacturing industry. Photo by Andrew Lucas; courtesy of LJ International Inc.



computer-aided diamond cut planning, highly precise robotic cutting for colored stones, and vacuum-casting in platinum. The industry is investing heavily in technology as well as staff skill level. The Chinese jewelry manufacturing industry faces the challenges of rising costs, consumer sophistication, value chain complexity, and global economic uncertainty. One of the biggest obstacles is the supply of rough material.

The Chinese manufacturing industry is already known for its appetite for rough colored stones (figure 26). During interviews at the 2013 Tucson gem shows, several U.S. dealers confirmed the difficulty of acquiring rough when trying to compete against China (Gemological Institute of America, 2013). Many dealers said they could not compete against the prices offered by Chinese cutting firms and jewelry manufacturers.

To feed the growing demand for colored stones, China is making investments in African nations to secure a supply of raw materials. One of the largest investments has been in developing African infrastructure, a strategy outlined in five-year plans since 2001 (Ashok, 2013). Some of these African locales produce diamonds. Zimbabwe, potentially a major diamond producer, is one of the countries where Chinese goods, services, and capital have been traded for rough diamonds since 2011 (Ashok, 2013), and so far this strategy has been successful. Between 2006 and 2011, when there was a 3% fall in global rough supply, China posted a 20% increase in rough diamond imports by weight and a 55% increase by value (Ashok, 2013). Diamond sourcing will remain a challenge as the global competition for rough intensifies.

China, once a primarily low-cost manufacturing center, faces the challenges of rising costs, greater consumer sophistication and demands, value chain complexity, and global economic uncertainty. The country now boasts a highly skilled workforce, state-of-the-art technology, and high-quality products, including gemstones and jewelry. These factors will help address most manufacturing concerns.

THE DOMESTIC GEM AND JEWELRY MARKET

While China has been a leading force for manufacturing and exports in the global jewelry industry, the most anticipated development has been the growth of its domestic market. The rise in wages, though a competitive challenge for China's manufacturing sector, has created great opportunities for its retail jewelry industry.

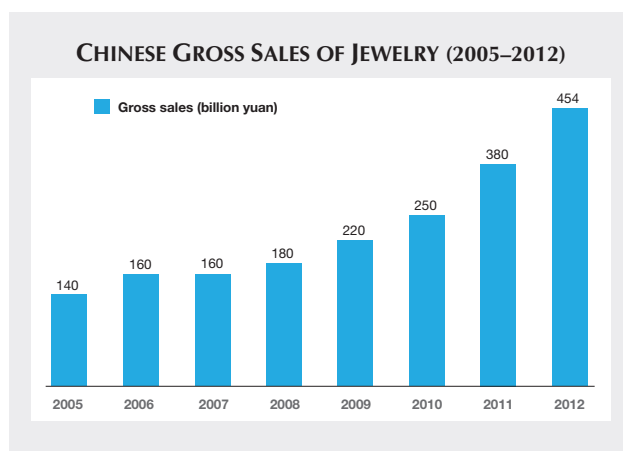


Figure 27. China's gross jewelry sales have grown impressively since 2005, with most years seeing double-digit growth. Data from China Economic Net (2012).

Domestic Jewelry Market. China is now the second-largest jewelry market in the world. Although there have been boom years and slower years, the overall growth has been remarkable (figure 27).

When gold prices plummeted in April 2013, Chinese consumers seized the opportunity to buy gold, including fine gold jewelry, at bargain prices. Retail sales for jewelry that month totaled 30.3 billion yuan (US\$5 billion), a 72.2% year-on-year growth (HKTDC Research, 2013).

While the growth of domestic jewelry consumption in China has been impressive over the last few years, there is still room for advancement. Per capita jewelry consumption is still relatively low compared

Figure 28. China's jewelry consumption per capita, though low compared to other major consumer countries, is on the rise, signaling strong potential for future growth. Data from China Economic Net (2012).

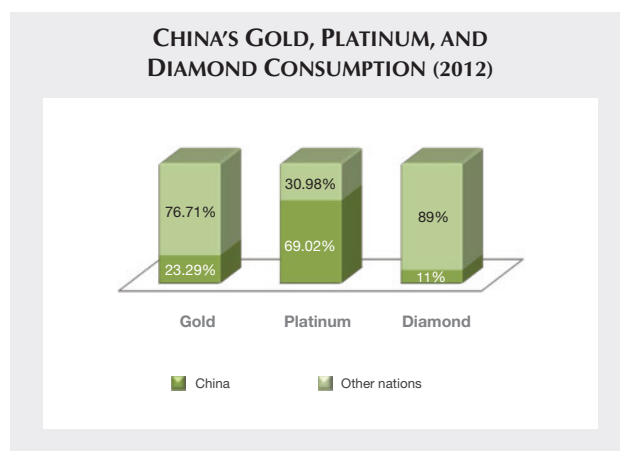
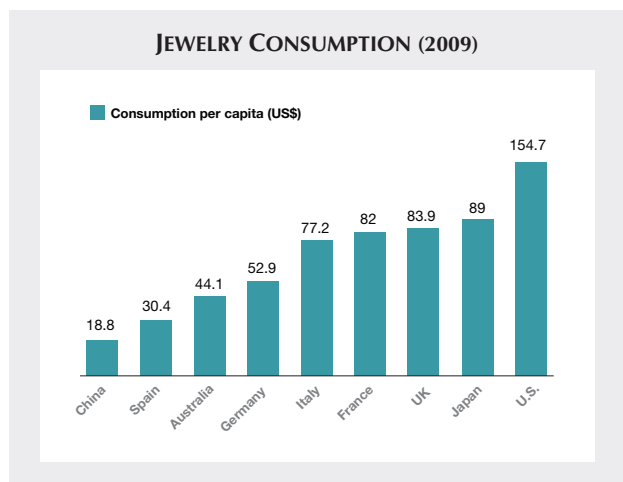


Figure 29. China consumes much of the world's gold, platinum, and diamond supply. Data adapted from "Diamond giant De Beers..." (2012); Johnson Matthey (2013); and China National Gold Group Corporation (2013).

to many other global markets (figure 28). Since 2009, jewelry consumption in both China and the United States has risen significantly, with China's consumption per capita more than doubling. Still, Michael Huang, managing director of the Diamond Index Group, noted that China's jewelry consumption still lagged far behind the major developed countries (Krawitz, 2013). China now has an estimated jewelry consumption per capita of US\$44, compared to Japan at \$91 and the U.S. at \$242 (Krawitz, 2013).

Gold Jewelry. As figure 29 demonstrates, fine gold jewelry is still a major seller in China. By 2012, China consumed 518.8 tons of gold jewelry and was the world's fastest-growing market for gold jewelry; more than 75% of Chinese women in urban areas own a significant piece of gold jewelry (World Gold Council, 2013). Two-thirds of Chinese women regard gold jewelry as more of an investment than an adornment. Yet in 2013, some 6.6 million Chinese brides were expected to receive gold as part of their wedding ceremony (World Gold Council, 2013). Clearly, gold also holds an emotional and sentimental value in China.

In the United States, diamond jewelry makes up a much higher percentage of overall jewelry consumption. But with the growth of the new consumer classes in China and the development of lower-tier cities, the domestic market for diamond and gemstone jewelry should continue to grow, with the market eventually becoming more diversified. This is already the case when one compares China's proportion of jewelry consumption categories to those of India and the United States (figure 30).

CHINA'S DIVERSIFIED JEWELRY MARKET

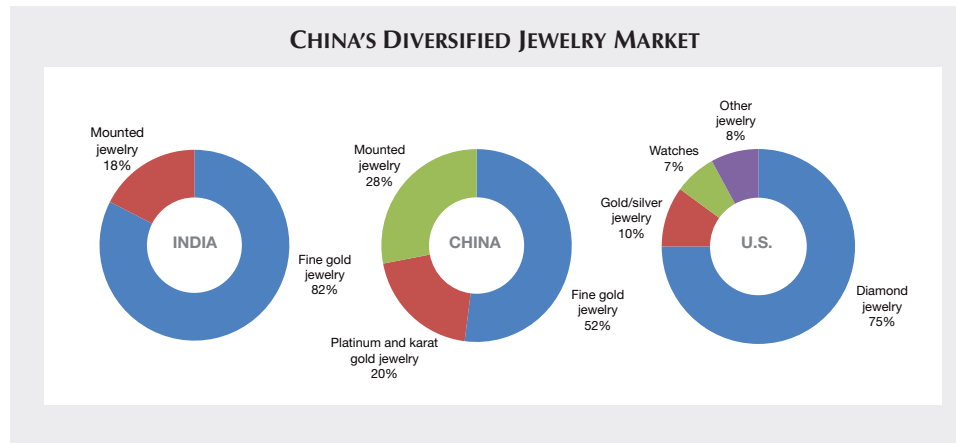


Figure 30. China's jewelry market is more diversified than India's, which is primarily focused on fine gold jewelry. Data from "2012 import and export statistics of the Chinese jewelry industry" (2013).

Chinese consumers traditionally have a strong preference for 24K gold jewelry because of its intrinsic value and the cultural affinity for purity. 24K gold accounts for more than 80% of the gold jewelry sold there (World Gold Council, 2013).

Gold has made inroads into the gem-set jewelry market, in both bridal and Western designer jewelry. In 2008, the World Gold Council collaborated with Chinese designers and manufacturers to create a line of 18K jewelry branded as K-Gold. This line was intended to inspire new designs and attract younger consumers seeking to combine tradition with innovation. The World Gold Council also launched advertising campaigns for two gold jewelry collections. These lines, the "Sign of Love" and the "Code of Love," capitalized on the tradition of gold jewelry as the first important gift in a romantic relationship.

By 2013, China was on track to overtake India as the world's largest consumer of gold (World Gold Council, 2013). That year, David Lamb, global managing director of jewelry and marketing for the World Gold Council, noted in an interview on the organization's website that more jewelry stores are opening in second- and third-tier cities. This reflects the greater consumer demand as these cities undergo economic development. In the same interview, he also mentioned a renewed interest in pure gold jewelry, as opposed to 18K and other karat gold jewelry.

Platinum Jewelry. China is the world's leading consumer of platinum, accounting for about 68% of the world's demand in 2012 according to Platinum Guild International. In a 2012 speech, Platinum Guild CEO James Courage noted that since 1997, PGI has invested US\$150 million into the Chinese market to promote the precious metal, an investment that has yielded a US\$4.3 billion net return to the platinum industry. Courage added that jewelry represented

about 31% of worldwide platinum consumption. Platinum jewelry purchases in China rose in by 16% over 2011, with 1.95 million ounces of platinum consumed as jewelry (Johnson Matthey, 2013).

In the Chinese market, women typically decide when to buy jewelry and what to purchase, whether it is a self-purchase or a romantic gift. Most of the platinum jewelry sold in China does not feature gems, but there has been an increasing trend to purchase it with gemstones, especially diamonds, for the bridal market. PGI's market research shows that platinum's natural white color and durability are seen as a fitting symbol for purity and a lifelong commitment in the Chinese bridal culture. (Stone Xu, pers. comm., 2013).

Mr. Courage described visiting Chinese platinum jewelry factories that employed more than a thousand people and produced tons of jewelry (Johnson Matthey, 2013). Major jewelry manufacturers in China often have large showrooms where retailers come and select the merchandise they want to buy for their stores. In fact, the showrooms in China are larger than the authors have seen in any other country, with cases full of inventory and buyers purchasing by the kilo. This general observation also applies to platinum jewelry.

Like other retail markets, China has seen a shift from stand-alone retail stores to jewelry sections in department stores and specialty malls for jewelry. This is especially true in the second- and third-tier cities. Department stores often showcase a variety of jewelry in high-traffic areas on the ground floor. According to PGI, platinum jewelry usually represents 10% to 20% of the entire jewelry inventory, a higher percentage than in other markets.

Consumers in second- and third-tier cities often buy 24K gold jewelry but aspire to be like their first-tier counterparts. PGI reports that in a cosmopolitan

city like Shanghai, 60% of the wedding rings purchased are platinum. As disposable income rises in lower-tier cities, PGI foresees a higher marriage rate and a higher percentage of platinum wedding rings. The same study notes that in larger cities, Chinese consumers are starting to adopt the Western trend of three-band wedding rings. This may also become the trend in second- and third-tier cities.

Silver Jewelry. China is the world's largest silver jewelry manufacturer. While industrial applications accounted for more than half of Chinese silver fabrication at 56%, jewelry fabrication accounted for 34% in 2011 (Silver Institute, 2012). Domestic consumption of silver jewelry rose dramatically as styles moved beyond the bulky traditional designs for weddings and birth celebrations. Younger Chinese consumers in first- and second-tier cities began to embrace silver jewelry after 2006, and most of the promotion has focused in these areas. Recently, consumers in rural areas have adopted silver jewelry as a lower-cost alternative to white gold and platinum. Rhodium-plated silver jewelry has also become popular, as it offers the look of platinum. Domestic manufacturers have been duplicating their gold jewelry lines in silver to provide lower-cost alternatives to a broad Chinese consumer market, especially entry-level customers.

Diamond Jewelry. China is now the second-largest diamond market, after the United States. Over the course of five years, diamond jewelry has grown from about one-quarter of China's total retail jewelry market to approximately one-third ("All that glitters...", 2013). China is also expected to lead diamond jewelry market growth, along with India, in the global market (Bain & Company, 2013). Much of this growth has come from accepting the Western tradition of giving diamond engagement rings and wedding rings. In China, there are an estimated 13 million brides per year ("All that glitters...", 2013). There has been a steady shift from gold wedding bands to diamond rings. According to Stephane Lafay, Tiffany's head of Asia Pacific and Japan, the number of urban people in China buying diamond engagement rings has risen from less than 1% to over 50% in the last 20 years ("All that glitters...", 2013). In turn, large Chinese jewelry companies that were built on 24K gold jewelry, such as Chow Tai Fook, have moved into the diamond jewelry market.

While growth has fluctuated since 2011, Kent Wong, managing director of Chow Tai Fook, noted that

RETAIL SALES OF DIAMOND JEWELRY IN CHINA

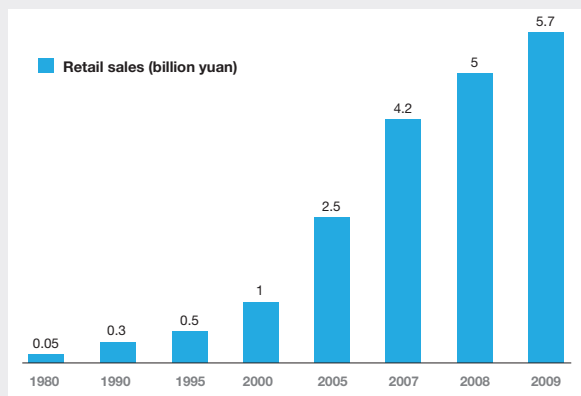


Figure 31. China has seen phenomenal growth in diamond sales over the last three decades (China Diamond Exchange Center, 2013).

the Chinese jewelry market was cyclical, especially during changes in the central government and its policies (Krawitz, 2013). With diamond's tradition as a symbol of love, eternity, and purity—and the relatively low per capita consumption today—growth seems almost inevitable. Add to that the Western-inspired trend of diamond jewelry as a gift for special occasions, along with the rise of diamond fashion jewelry, and it is clear to see why many in the industry are looking to China for growth.

In 2012, Rio Tinto released results from a study by the global market research company Ipsos that showed the Chinese consumer was becoming more open to affordable, fashion-flexible diamond jewelry ("Rio Tinto research confirms strong potential...", 2012). While diamond consumption in China represents a far lower percentage of global consumption than gold or platinum, the market shows enormous growth potential (figure 31).

Colored Gemstones. In recent years, especially since 2010, China's consumption of jewelry has expanded to colored gemstones. While retail colored stone sales have been highest in first-tier cities, second-tier purchasers are close behind (table 5). As consumers in third- and fourth-tier cities earn more discretionary income, their retail consumption of colored stones should also increase substantially.

Many dealers at the 2013 Tucson gem shows reported a rebound in U.S. customer sales and a strong presence of Chinese buyers (Gemological Institute of America, 2013). They also noted dramatic price increases that were primarily due to Chinese consumption. In fact, several dealers pointed to problems

TABLE 5. Colored stone retail sales in China by year (billion yuan).

	2007	2008	2009	2010	2011
Gross retail sales	4.3	5.4	7.2	9.6	13.4
First-tier cities	1.8	2.2	3.0	4.0	5.6
Second-tier cities	1.6	2.0	2.7	3.7	5.1
Third-tier cities	0.6	0.8	1.0	1.4	1.9
Other	0.3	0.4	0.5	0.6	0.7

Data compiled from Lu (2013).

replenishing their inventory. In the words of one U.S. colored stone dealer, “I went to a mine to buy rough, and a Chinese buyer had already been there and bought their production. When I returned six months later, the Chinese had purchased the mine.”

Dealers at the 2013 Tucson shows reported that Chinese buyers were interested in a wider variety of colored stones than in years past. Red is traditionally a popular color in China, and ruby and rubellite tourmaline (figure 32) have been popular there for many years. In fact, many trade members have attributed skyrocketing prices for those two gems to the Chinese market. When Christie’s held its first jewelry auction in mainland China in Shanghai on September 26, 2013, a ruby and diamond necklace com-

manded the highest bid, at \$3.4 million (“Ruby necklace tops Christie’s first China auction,” 2013). Based on the authors’ observations and feedback from the industry, other red and pink gemstones such as spinel, garnet, rose quartz, and red jasper also appear to be gaining a following in China.

Gemstones in other colors are also in demand. Multicolored tourmaline jewelry is becoming more popular in response to the rising price of rubellite (“Tourmaline grips Chinese collectors,” 2013). Both blue and green tourmaline, alongside other blue gems like sapphire, aquamarine, blue topaz, and even lesser-known gems like cat’s-eye siliminate, are gaining a foothold in the Chinese market (“Blue and green gems on the rise...,” 2012). Blue to violet tanzanite has become especially popular. Recently, the large retailer Chow Tai Seng, with 2,200 stores domestically, was named a “retail polished sightholder” with TanzaniteOne (Max, 2013), which demonstrates the Chinese market’s openness to nontraditional colored stones. China’s consumers have become aware of all the gemstone choices, and more of these choices at many price points are now available to them.

Enzo, the retail division of LJ International, recently acquired a copper-bearing tourmaline mine in Mozambique (figure 33). With 250 retail stores in mainland China, Enzo hopes to popularize this rare and unusually vivid gemstone domestically (Lorenzo Yi, pers. comm., 2013). These tourmalines are being promoted through advertising, the trade media, and celebrity endorsement.

One of the biggest challenges facing the Chinese colored gemstone industry, for both exports and domestic consumption, is sourcing material (Wilson Yuan, pers. comm. 2013). The fierce competition for many varieties of colored stones, particularly finer-quality material, has also been felt in other manufacturing centers such as India, Thailand, and Sri Lanka. As Chinese consumer demand has grown, the price of colored rough has soared. These price increases

Figure 32. China has become a consumer of rubellite tourmaline from sources around the world, including these Nigerian rubellites. Photo by Robert Weldon.





Figure 33. Blue and green tourmaline, like this copper-bearing stone from Mozambique that sold to a Chinese buyer at the September 2013 Hong Kong show, are increasingly in demand in China. Photo by Andrew Lucas; courtesy of Lorenzo.

have had some positive global effects. For instance, some mines that were not previously economically viable (such as rubellite mines in Brazil) are now able to operate.

Jadeite. While jadeite does not have as long a history in China as nephrite, it is still one of the country's most popular gem materials. The Guangdong Province Jade Association notes that since the late 1990s, thousands of tons of rough jadeite have been imported through the port of Guangzhou (Tingxin Li, pers. comm., 2013). The jadeite is carved or manufactured locally, making Guangdong the national hub of jadeite manufacturing and sales. The Pingzhou region of Guangdong, China's largest jadeite rough market, is referred to as the "hometown" of the jadeite bracelet (figure 34). More than 20 auctions are held here each year, attracting dealers and retailers from all over the country. The Sihui area draws carvers from Putian and Nanyang, who apply skills and concepts from wood and stone carving to jadeite.

Another important entry point lies along the border between China and Myanmar in Yunnan province, China's earliest jadeite import locale. There were about 6,000 jadeite companies in Yunnan in 2007; five years later, this number had increased to 21,000 (Tingxin Li, pers. comm., 2013). The main markets there are concentrated in Tengchong, Yingjiang, and Ruili.

From 2000 to 2009, the price of jadeite rose by an average of 20% annually. For 2011 and 2012, this rate increased more than 30% annually (China Industrial Information Network, 2013). Myanmar, which produces much of China's jadeite, wants to strictly con-



Figure 34. The Pingzhou area of Guangzhou is known for manufacturing jadeite bangle bracelets. This man is drilling the shape from a precut circular piece of jadeite. Photo by Eric Welch.

trol its export and develop its own mine-to-market business, even as the Chinese demand for high-end jadeite continues to grow. Some jadeite dealers were forced to tap into their reserves to deal with the lack of rough. At the June 2013 Myanmar jadeite auction, rough prices skyrocketed. In total, fewer than 10,000 pieces were available for purchase (compared to 20,000–30,000 pieces in previous auctions), while prices were three to ten times higher (Chen, 2013). Trade experts from both Yunnan and Guangdong said the retail price of high-quality jadeite increased at about the same rate as the rough price; medium- to low-quality jadeite was not as affected. The price hike was not well received by Chinese consumers, who did not want to spend much money on lower-quality material (Tingxin Li, pers. comm., 2013). High-end jadeite products are still in demand among Chinese collectors and investors—in China and around the world—even at significantly marked-up prices.

IMPORT AND EXPORT

Looking at imports of jewelry by country (figure 35, left) and value, the importance of the EU and its branded luxury jewelry lines to China's market is evident. The import value is even more impressive when one considers all the purchases of European jewelry made by Chinese consumers traveling abroad. At the other end of the import range are low-end commercial lines from India.

The significance of the "one China, two systems" policy governing mainland China and Hong Kong becomes clear when looking at China's jewelry exports

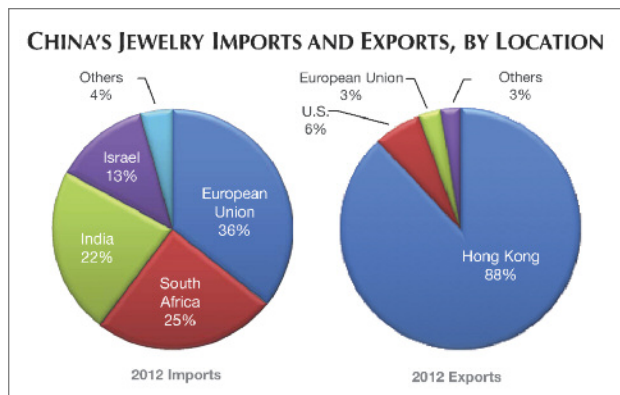


Figure 35. Left: Jewelry from the European Union is a significant amount of the total jewelry imports into China reflecting the luxury brands from that country. Right: The percentage of Chinese jewelry exports to Hong Kong reflects that city's status as the gateway from China to the global market. Data from "2012 Import and Export Statistics of the Chinese Jewelry Industry" (2013).

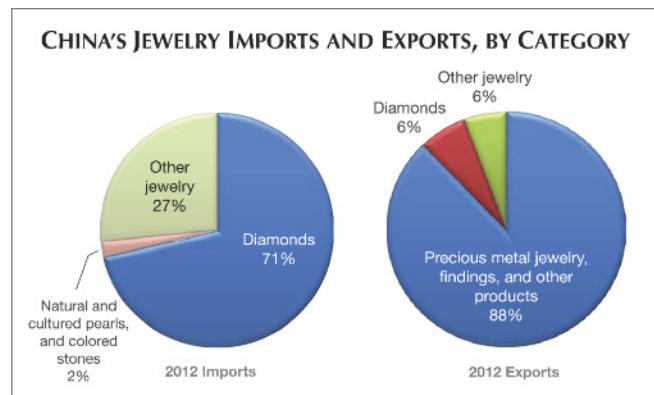


Figure 36. Left: Diamond jewelry is the largest category of jewelry imported into China. Right: Precious metal jewelry and findings is the largest category of jewelry exported from China. Data from "2012 Import and Export Statistics of the Chinese Jewelry Industry" (2013).

by country. Although Hong Kong is part of China, it is also a free trade area and in an excellent position to serve as China's export center. In 2012, 88% of China's jewelry was exported to Hong Kong (figure 35, right), most of it for distribution in the global market.

Diamond jewelry represents the largest percentage by value of jewelry imports into China, at 71% in 2012 (figure 36, left). This is partly due to the efficient import channels via the Diamond Exchange, the VAT refund lowering the cost of diamond jewelry to Chinese consumers, and the inherent value of the product. As seen in figure 36 (right), China is a major supplier of jewelry to the global market; the largest category of export is findings and precious metal jewelry. Diamond and gemstone jewelry have significant room for expansion in the overall percentage of exports, while imports and exports of colored gemstones and cultured pearls have seen consistent gains (table 6).

SUMMARY

China is currently the second-largest jewelry consumer in the world. Its economy has shown phenom-

enal growth and resilience over the last 30 years, averaging around 10% annually. Although its growth is expected to slow over the next several years, China may still overtake the U.S. within the next decade. The latest five-year national plan, issued in 2011, emphasizes sustainable growth coupled with policies to develop domestic consumption. Large numbers of Chinese citizens are expected to migrate to cities over the next decade, and less-developed inland cities are specifically targeted for growth. As discretionary income grows, particularly in the third- and fourth-tier cities, so should domestic consumption of goods, especially luxury goods such as jewelry. Meanwhile, China's Generation 2, born after the mid-1980s, is considered global-minded and open to Western-style product consumption. Their confident outlook on the future is a positive signal for discretionary spending.

Brands and quality considerations rank very high among Chinese consumers, although brand expectations vary. For instance, residents of lower-tier cities tend to purchase goods with conspicuous logos, while shoppers in the cosmopolitan coastal cities

TABLE 6. Chinese imports and exports of gemstones and natural and cultured pearls (in billion US\$).

	2005	2006	2007	2008	2009	2010	2011
Imports	3.5	4.6	6.3	7.5	6.5	10.8	14.9
Exports	5.5	6.9	8.1	8.5	7.5	12.5	27.5

Source: United Nations Commodity Trade Statistics Database (2013).

favor understated sophistication. Chinese luxury consumers tend to be younger than their U.S. and European counterparts and are already predisposed to consider luxury goods a necessity. With the success of e-commerce campaigns, such as Singles' Day on November 11, the continued growth of Chinese consumption seems almost a foregone conclusion.

When China reopened to the world market, jewelry businesses in Hong Kong took advantage of lower-cost labor in Guangdong province and the newly established free trade zones. The "one China, two systems" policy, which has maintained a free market in Hong Kong since reunification in 1997, stimulated rapid growth in Chinese exports. Some of these same jewelry businesses from Hong Kong moved into the domestic Chinese market as it took off. The creation of the Shanghai Diamond Exchange and the Shanghai Gold Exchange led to the reform of import and export protocols, including revision of tax policies, and this fueled the growth of the domestic jewelry industry. While rising labor costs are a concern to China's jewelry manufacturing industry, the adoption of technology and the move to the high-end market have kept it competitive globally.

China's consumption per capita of jewelry is low compared to the United States, but it is rising at a dramatic rate. The success of platinum in a relatively short time shows an openness to new products. Diamond jewelry has been very popular in China, especially in the bridal market, and diamond fashion jewelry is also considered a new sector for growth. A variety of colored stones are being marketed and gaining interest in the domestic market. The global markets for colored gemstones such as ruby, rubellite, and tourmaline have already been profoundly impacted by Chinese consumers (figure 37). Other stones such as tanzanite are gaining considerable traction, while the more traditional jadeite remains extremely popular.

While it remains a global manufacturing leader,



Figure 37. Colored stones, like other sectors of the gem and jewelry industry, have gained great popularity in China over the past several years, a trend that is expected to continue. Photo courtesy of China Gems magazine.

China is also developing and diversifying its domestic jewelry market. Although the country faces challenges such as wealth disparity, environmental issues, and bureaucratic obstacles, China's dynamic gem and jewelry industry seems destined for an even brighter future.

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NEAR-COLORLESS HPHT SYNTHETIC DIAMONDS FROM AOTC GROUP

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The gemological and spectroscopic properties of 52 colorless to fancy light-colored HPHT synthetic diamonds (40 of them colorless or near-colorless) produced by AOTC using either toroid- or BARS-press technologies were characterized. In addition to achieving excellent color grades, these commercially available faceted synthetics had a weight range of 0.05 to 0.80 ct, and possessed IF to I₂ clarity. Their synthetic origin may be difficult to determine with standard gemological techniques alone, but they were conclusively identified using advanced testing methods, including photoluminescence, FTIR spectroscopy, and fluorescence imaging. Inclusions in two samples, grown by different press types, were studied using LA-ICP-MS. The trace-elemental analysis results indicated that the inclusions formed by the trapping of the solvent/catalyst melt during synthesis. Analysis of the combined multi-technique data provided insight into the identities of the solvents, catalysts, and nitrogen getters possibly used to grow high-quality HPHT synthetic diamonds.

In the gem trade, natural diamonds with D to Z color are significantly more abundant than their fancy-color counterparts. The opposite is true for gem-quality synthetic diamonds, where near-colorless specimens are more challenging to produce. Most synthetic diamonds used for jewelry are produced by either high-pressure, high-temperature (HPHT) or chemical vapor deposition (CVD) techniques. Advances in CVD technologies, as well as an improved understanding of the growth processes, led to the introduction of near-colorless CVD synthetic diamonds around the middle of the last decade (Wang et al., 2007) by companies such as Apollo Diamond Inc. (sold in 2011 to Scio Diamond Technology). More recently, the near-colorless CVD synthetic diamond market has expanded with the large-scale production from Gemesis Corporation, which reportedly applies color-enhancing post-growth treatments to its as-grown material (Wang et al., 2012a). CVD synthetics have garnered significant publicity based on instances where samples have been submit-

ted to gemological laboratories without disclosure of their unnatural origin (Even-Zohar, 2012).

Although well known in the colored diamond market, HPHT-grown synthetics have not played a significant role in the mainstream colorless diamond trade. Most colorless to near-colorless faceted HPHT synthetic specimens have been grown solely for research purposes by companies such as General Electric (Crowningshield, 1971; Koivula and Fryer, 1984; Shigley et al., 1993), De Beers (Rooney et al., 1993; Burns et al., 1999), and Sumitomo Electric Industries (Shigley et al., 1997; Sumiya and Satoh, 1996; Sumiya et al., 2002). Near-colorless HPHT synthetics have also been marketed within the gem trade, in notably limited quantities, by Chatham Created Diamonds, Starcorp, and Advanced Optical Technology Corporation (AOTC), now trading as AOTC Group, B.V. (see Koivula et al., 1994; Shigley et al., 1997; Deljanin et al., 2006; D'Haenens-Johansson et al., 2012).

In 2012, three near-colorless and three faintly colored HPHT-grown AOTC synthetic diamonds were submitted to GIA's New York laboratory for grading services. These samples, in addition to 24 colorless, near-colorless, faintly colored, and lightly colored faceted HPHT synthetics on loan from AOTC, were studied and briefly reported on in *Gems & Gemology* (D'Haenens-Johansson et al., 2012). GIA subse-

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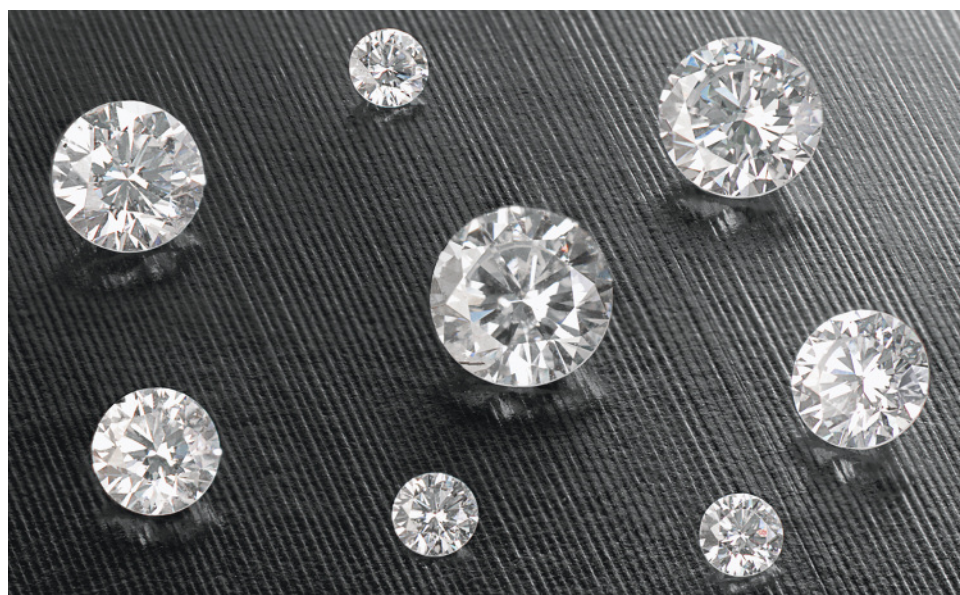


Figure 1. This photograph shows eight of the 52 faceted HPHT synthetic diamonds obtained from AOTC Group, ranging from 0.05 to 0.57 ct. Of the total suite of samples examined, 40 were graded as colorless to near-colorless, a remarkably good color range for HPHT synthetic diamonds, which are commonly produced in fancy colors. Photo by Josh Balduf.

quently obtained another 22 samples from AOTC, including 10 melee-sized synthetic diamonds. This article will present the results of the investigation using gemological and spectroscopic techniques on the full suite of 52 AOTC synthetic diamonds (selected samples are shown in figure 1). Although their properties are comparable to those of top-quality natural diamonds, it is still possible to identify them as HPHT synthetics.

AOTC is a privately owned synthetic gem diamond company headquartered in the Netherlands, with offices in Germany, Switzerland, Canada, and the United States. AOTC's faceted HPHT synthetic diamonds can be purchased through their company website (by members of the jewelry trade only) or through D.NEA, an online retail operation that sells their synthetics, both loose and in jewelry pieces. The products retail with full disclosure of their laboratory origin, and samples weighing more than 0.30 ct bear the laser inscription "AOTC-created" (D.NEA, 2014a). Although most of its production is focused on fancy-color yellow and blue HPHT synthetics, AOTC also grows near-colorless (labeled "white") synthetic diamonds using BARS- and toroid-press technologies. The company's yellow HPHT synthetic diamonds are sold in sizes up to 3 ct; however, the blue and "white" synthetics weigh no more than 1.5 ct (D.NEA, 2014b). Since these products are only available in faceted form, the as-grown "rough" specimens are considerably larger. D.NEA (2014c) reports selling its "white" synthetic diamonds at prices "15–40% less than comparable mined diamonds." Currently, AOTC is the domi-

nant producer of near-colorless HPHT synthetic diamonds for the gem trade.

REVIEW OF HPHT SYNTHESIS OF DIAMOND

Diamond synthesis by HPHT methods was first carried out by the Swedish company ASEA in 1953, but the synthetic diamond era truly began a year later, when scientists at General Electric (GE) independently reported the growth of diamond using this technique (Bundy et al., 1955). Prior to GE's success, diamond and graphite had already been established as carbon *allotropes* (i.e., consisting of different structural configurations of the same element). It was originally thought that applying high temperatures and pressures to graphite, to some extent mimicking the growth conditions of natural diamond, would yield synthetic diamond, but this proved unsuccessful.

Through research, the process evolved into the temperature-gradient HPHT method. In this method (Bovenkerk et al., 1959), the HPHT capsule is filled with the carbon source material (typically graphite), a diamond "seed," and a solvent/catalyst (usually a group VIII element such as iron or its alloys). The use of a solvent/catalyst lowers the temperature and pressure conditions necessary for successful diamond growth. Alloys such as Fe-Ni and Fe-Co are widely used because of their lower melting points (and thus lower pressures required). The system's pressure and temperature are increased so that the solvent/catalyst melts; the resulting diamond is the thermodynamically stable form of carbon. The conditions vary depending on the size, quality, and type of diamond synthesized, but the pressures and temperatures ap-

plied are usually in the ranges of 5–6 GPa and 1300–1600°C, respectively (Burns et al., 1999). A temperature gradient (i.e., difference in temperature) is carefully produced, such that the carbon source material is located in a hotter region than the diamond seed. The source material dissolves, and the carbon atoms are transported toward the cooler region, where the dissolved carbon becomes supersaturated in the solvent, crystallizing on the diamond seed and forming new diamond. Four main types of presses are used to grow diamond by this method: belt, BARS (based on a split-sphere concept), cubic, and toroid presses (see e.g. Strong and Chrenko, 1971; Strong, 1989; Bundy et al., 1973; Shigley et al., 1993; Khvostantsev et al., 2004).

Chemical impurities and macroscopic inclusions from the solvent/catalyst are easily incorporated into the growing diamond. Nitrogen contamination may originate from the solvent/catalyst, the carbon source, or the gas found in the empty spaces or pores of the HPHT capsule. The nitrogen impurities enter the structure of the nascent diamond as substitutional atoms, resulting in yellow type Ib material with nitrogen concentrations in the range of 100 to 300 atomic parts per million (Burns et al., 1999). Most of the HPHT synthetic diamonds produced worldwide are type Ib. Synthesis time and temperature conditions permitting, the isolated nitrogen atoms may also aggregate into pairs, forming A-centers and resulting in mixed type Ib/IaA synthetic diamonds (Chrenko et al., 1971 and 1977).

To reduce impurity concentrations and create near-colorless type IIa or weak type IIb diamonds, it is insufficient to merely use higher-purity solvents/catalysts and carbon sources. It is also necessary to introduce a *nitrogen getter*, usually an element with a strong affinity for nitrogen, such as aluminum (Al), titanium (Ti), zirconium (Zr), or hafnium (Hf). A significant amount of the nitrogen in the growth capsule will thus be “trapped,” forming nitrides. Nevertheless, the introduction of the nitrogen getter may promote the uptake of solvent/catalyst inclusions, due to the reduced solubility of the carbon in the solvent/catalyst or changes in the diffusion of the carbon. To minimize this effect, it may be advantageous to slow the growth rate by adjusting the temperature. The nitrogen getter may also react with the carbon to form carbides that can be incorporated in the HPHT synthetic diamond, reducing its clarity. A suitable element (such as copper) may be further added to decompose these carbides (see Strong and Chrenko, 1971; Burns et al.,

1990; Sumiya and Satoh, 1996; Sumiyu et al., 1996).

Type IIb synthetic diamonds with colors ranging from pale blue to opaque blue-black can also be created by doping the material with boron. To do this in a controlled manner, the nitrogen concentration is simultaneously reduced by adding nitrogen getters. The blue color arises from uncompensated boron, or the amount of boron in excess of the substitutional nitrogen concentration at the atomic ppm level (Burns et al., 1999).

Fancy-color HPHT synthetic diamond products, available to the gem trade since the early 1990s, have been extensively characterized (e.g., Shigley et al., 1993b, 2002). The complex mixture of ingredients in the growth capsule, combined with the need for sensitive control of temperature and pressure for extended periods of time, has made near-colorless HPHT diamond synthesis expensive and time consuming. Consequently, fewer near-colorless samples are available for study (Koivula et al., 1994; Shigley et al., 1997; Deljanin et al., 2006; D’Haenens-Johansson et al., 2012). AOTC indicates it can take more than two weeks to grow a synthetic “white” crystal that can be cut into a 1 ct synthetic diamond (D.NEA, 2014b). By comparison, AOTC states that growth periods for yellow and blue HPHT synthetic diamonds are 5–6 days and 7–10 days, respectively (D.NEA, 2014d,e). There is no post-growth treatment known to reduce color saturation in near-colorless HPHT synthetic diamonds, and AOTC claims to sell its “white” products in the as-grown state (D.NEA, 2014b). Although near-colorless HPHT synthetic diamond manufacturing for gem applications did not become commercially viable until recently, Sumitomo Electric Industries launched its Sumicrystal type IIa HPHT synthetic product in 1996. The company has reported the synthesis of diamonds as large as 8 ct for industrial applications (Sumiya and Satoh, 1996; Sumiya et al., 2002, 2005).

MATERIALS AND METHODS

All 52 of the faceted HPHT synthetic diamonds were round brilliants, ranging from 0.05 to 0.80 ct. Excluding the 10 melee-sized samples (all measuring 0.05 ct), the average weight was 0.37 ct. According to AOTC, 40 of the samples were grown using BARS presses, while the remaining 12 were created in toroid presses. Color and clarity grades were determined using the standard GIA grading systems for D to Z and fancy-color diamonds. Inclusions were investigated using a standard gemological binocular microscope system, as well as a Nikon SMZ1500 microscope with darkfield and fiber-optic illumination. The samples were also

examined under magnification between two crossed polarizing filters to detect anomalous birefringence (usually caused by strain). The color and clarity grades given in this article are for research purposes only. GIA's standard practice for synthetic diamond grading reports is to provide a color and clarity grade range.

Electrical conductivity was tested using a GIA electroconductometer, and magnetic properties were evaluated by suspending the sample from a thin thread and checking for motion when a strong magnet was brought toward it (Koivula and Fryer, 1984).

The samples' fluorescence and phosphorescence behavior to short- (254 nm) and long-wave (365 nm) ultraviolet light was investigated using a standard four-watt combination gemological testing lamp in a dark room. Additionally, fluorescence and phosphorescence images (5.0 second exposure and 0.1 second delay) were recorded using a DTC DiamondView instrument (< 230 nm excitation). Room-temperature phosphorescence spectra were collected using an Ocean Optics HR4000 spectrometer coupled with an Avantes-DH-S deuterium-halogen light source (215–2500 nm), as described by Eaton-Magaña et al. (2007, 2008). The experiment consisted of illuminating the sample for 20 seconds, switching off the light, and collecting phosphorescence spectra (1 second integration time) for a period of 120–180 seconds.

Room-temperature infrared absorption spectra were collected over the 6000–400 cm^{-1} range, at a resolution of 1 cm^{-1} , using a Thermo Nicolet Nexus 6700 FTIR spectrometer equipped with KBr and quartz beam splitters and a DRIFT (diffuse-reflectance infrared Fourier transform) unit. The system was purged with nitrogen gas to reduce absorption features from atmospheric water and carbon dioxide. IR spectra were normalized using the method of Palik (1985) to allow for calculation of defect concentrations.

Photoluminescence (PL) spectra were collected using a Renishaw InVia Raman confocal microspectrometer equipped with four laser systems, producing six excitation wavelengths: 324.8, 457.0, 488.0, 514.5, 632.8, and 830.0 nm. Samples were immersed in liquid nitrogen in a specially designed double-layer bath (patent pending) to maintain temperature at 77K (–196°C). Additional PL data were acquired using a Horiba XploRA Raman confocal microspectrometer with a 532.0 nm laser.

Trace-element analysis was conducted on surface-reaching inclusions in two samples, B0124 and T0130 (BARS- and toroid-press grown, respectively), using a ThermoFisher X-Series II laser ablation–inductively coupled plasma–mass spectrometer (LA-ICP-MS)

equipped with a 213 nm laser ablation system. NIST SRM 610 and 612 glass standards were used for internal calibration. The system was run with a 7 Hz repetition rate and 16.09 J/cm^2 fluence. Spot sizes of 25 μm (B0124) or 30 μm (T0130) were chosen to ensure that only the inclusion material was sampled. The inclusions in B0124 and T0130 were laser-ablated for 45 and 30 seconds, respectively.

RESULTS

Color. As shown in table 1, most of the samples were graded as colorless in the D–F range (33%) or near-colorless in the G–J range (44%). Notably, the largest specimen (B0141, weighing 0.80 ct) had an impressive G color grade. The remaining samples displayed enough blue, green, or yellow-green coloration to be-

In Brief

- The 52 faceted colorless and near-colorless HPHT synthetic diamonds from AOTC studied in this report ranged in size from 0.05 to 0.80 ct, with 77% achieving colorless or near-colorless grades. Clarities ranged from IF to I_2 .
- The HPHT synthetics were grown using BARS- and toroid-press technologies. PL and FTIR absorption spectroscopy, combined with trace element analysis of inclusions using LA-ICP-MS, suggest that different solvent/catalyst melts may be used during their synthesis.
- Although visual inspection may be insufficient to recognize their laboratory-grown origin, these samples could be positively identified as HPHT synthetic diamonds using PL spectroscopy and DiamondView fluorescence imaging.

graded on the fancy color scale, with the strongest color saturation resulting in a Fancy Light blue grade. The color distribution in the latter samples was unusually even, without the zoning frequently observed in HPHT synthetics.

Microscopy. The clarity of the suite ranged from IF to I_2 , with no correlation between color and clarity grades (table 1). The melee-sized samples (B0152–B0162) had good clarity overall, with most receiving grades of VVS_2 or higher, including two IF samples. The poorer clarities resulted from elongated solvent/catalyst inclusions, which were opaque or metallic in appearance (figures 2 and 3), or from feathers. The results imply that samples grown using toroid presses are more likely to have distinct inclusions under 10 \times magnification, as nine of the 12 sam-

TABLE 1. Gemological properties and calculated bulk concentrations of neutral boron ($[B^0]$) impurities for HPHT synthetic diamonds from AOTC.^a

Sample	Growth apparatus	Weight (ct)	Color	Clarity	Magnetic	Electrically conductive	$[B^0]$ bulk concentration (ppb)
B0117	BARS	0.22	Faint blue	VS ₂	No	Yes	38 ± 5
B0118	BARS	0.34	F	VVS ₂	No	No	-
B0119	BARS	0.28	F	VS ₁	No	No	8 ± 1
B0120	BARS	0.30	Fancy Light blue	VS ₂	Yes	Yes	216 ± 30
B0121	BARS	0.26	F	VS ₂	Yes	No	3.2 ± 0.5
B0122	BARS	0.38	Very Light blue	SI ₂	Yes	No	62 ± 9
B0123	BARS	0.39	H	I ₁	No	Yes	21 ± 3
B0124	BARS	0.41	G	VS ₂	Yes	No	7 ± 1
B0125	BARS	0.42	H	SI ₁	Yes	Yes	47 ± 7
B0126	BARS	0.45	Very Light blue	SI ₁	Yes	Yes	57 ± 9
B0127	BARS	0.54	J	VS ₁	No	No	4.7 ± 0.7
B0128	BARS	0.57	J	VVS ₁	No	No	12 ± 2
T0129	Toroid	0.20	H	I ₁	No	No	-
T0130	Toroid	0.33	H	I ₂	Yes	No	-
T0131	Toroid	0.32	I	I ₂	Yes	No	-
T0132	Toroid	0.32	G	I ₂	Yes	No	-
T0133	Toroid	0.21	H	VS ₂	No	No	-
T0134	Toroid	0.21	I	VVS ₁	No	No	-
T0135	Toroid	0.23	I	VVS ₁	No	No	-
T0136	Toroid	0.23	F	I ₁	Yes	No	-
T0137	Toroid	0.25	G	I ₂	Yes	No	-
T0138	Toroid	0.25	F	I ₂	Yes	No	-
T0139	Toroid	0.25	G	I ₁	Yes	No	N/A
T0140	Toroid	0.27	J	I ₁	Yes	No	-
B0141	BARS	0.80	G	VVS ₁	N/A	N/A	49 ± 7
B0142	BARS	0.60	F	IF	N/A	N/A	-
B0143	BARS	0.58	H	I ₁	Yes	No	-
B0144	BARS	0.51	Very Light green	SI ₁	Yes	No	94 ± 15
B0145	BARS	0.46	F	SI ₁	Yes	No	25 ± 4
B0146	BARS	0.40	E	SI ₁	Yes	No	21 ± 3
B0147	BARS	0.40	F	SI ₁	Yes	No	13 ± 2
B0148	BARS	0.31	Very Light yellowish green	VS ₁	No	No	17 ± 3
B0149	BARS	0.30	G	VS ₂	Yes	No	32 ± 5
B0150	BARS	0.30	Faint blue	VVS ₁	Yes	No	26 ± 4
B0151	BARS	0.29	G	SI ₂	Yes	No	13 ± 2
B0152	BARS	0.24	Faint yellow-green	VVS ₁	No	Yes	4.3 ± 0.6
B0153	BARS	0.05	F	VVS ₁	No	No	47 ± 7
B0154	BARS	0.05	H	VVS ₁	No	No	-
B0155	BARS	0.05	E	VVS ₁	No	No	30 ± 5
B0156	BARS	0.05	Faint blue	VVS ₁	No	Yes	120 ± 20
B0157	BARS	0.05	D	VVS ₂	No	No	49 ± 7
B0158	BARS	0.05	I	VVS ₂	No	No	-
B0159	BARS	0.05	E	VVS ₁	No	No	25 ± 4
B0160	BARS	0.05	E	IF	No	No	31 ± 5
B0161	BARS	0.05	F	VVS ₁	No	No	100 ± 15
B0162	BARS	0.05	E	IF	No	No	23 ± 3
B4122	BARS	0.57	G	VS ₁	No	No	4.1 ± 0.6
B4123	BARS	0.54	F	VVS ₁	No	No	2.6 ± 0.4
B4124	BARS	0.50	Very Light blue	VS ₂	Yes	Yes	90 ± 10
B4125	BARS	0.42	Faint blue	SI ₁	Yes	Yes	42 ± 6
B4126	BARS	0.35	H	SI ₁	Yes	No	-
B4127	BARS	0.33	Faint blue	SI ₁	Yes	Yes	36 ± 5

^a $[B^0]$, averaged across the whole sample, was calculated using the integrated intensity of the 2800 cm⁻¹ feature in the FTIR absorption data. N/A: not analyzed.

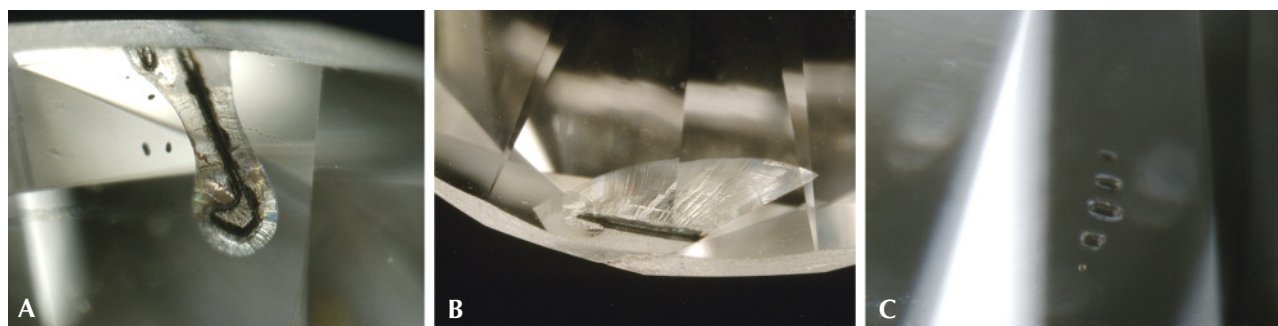


Figure 2. Some of AOTC's HPHT synthetic diamonds contained dark metallic inclusions, which were often rod-shaped. Surface-reaching feathers or fractures surrounding the inclusions were also observed. The photomicrographs for samples B0124 (A), B0143 (B), and B0149 (C) have image widths of 1.20, 2.40, and 1.05 mm, respectively. Inclusions in toroid-grown samples (not shown) were similar. Photomicrographs by Ulrika F.S. D'Haenens-Johansson.

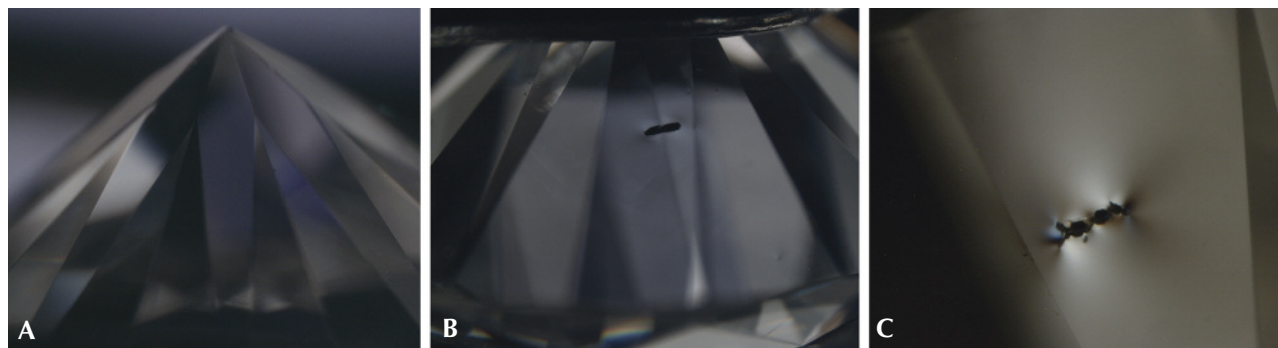
ples received I₁–I₂ clarity grades. Graining was not observed in any of the AOTC samples. This is consistent with the subdued interference colors (gray/blue) displayed under crossed polarizers, as shown in figure 3, which indicate the low levels of strain characteristic of HPHT synthetic diamonds (Crowningshield, 1971). Higher levels of strain were only seen directly adjacent to inclusions or feathers.

Fluorescence and Phosphorescence. None of the samples showed fluorescence reactions under a handheld gemological long-wave UV lamp. Under short-wave UV, however, most displayed weak to strong greenish yellow fluorescence, with only 17% remaining inert. Fluorescence color zoning was not observed. The intensity of the fluorescence increased with exposure time, stabilizing after a few seconds. The fluorescing samples exhibited phosphorescence that was initially yellowish green but rapidly turned

greenish blue. The greenish blue component was unusually long lasting, continuing for more than six minutes for some of the most intensely fluorescent samples. Stronger fluorescence to short-wave rather than long-wave illumination with a gemological lamp is one of the distinctive features of HPHT synthetic diamonds, as noted in the literature (Crowningshield, 1971; Koivula and Fryer, 1984; Rooney et al., 1993; Shigley et al., 1993, 1997). Fluorescence and phosphorescence colors were consistent with some of the near-colorless HPHT synthetic samples studied by Shigley et al. (1997).

DiamondView fluorescence images revealed cuboctahedral growth patterns typical of HPHT synthetics. The patterns form due to growth sector-dependent differences in a sample's impurity uptake, where a growth sector is defined as a three-dimensional region of the crystal with a common crystallographic growth plane (Burns et al., 1990, 1999). At

Figure 3. (A) Viewed between crossed polarizers, the AOTC samples displayed weak low-order interference colors and no discernible anomalous double refraction pattern, signifying very low levels of strain. Highly strained regions were only observed adjacent to fractures or inclusions, such as those shown in images B and C. These images are from samples B4123, B4127, and B0144, with image widths of 2.20, 2.65, and 1.25 mm, respectively. Photomicrographs by Ulrika F.S. D'Haenens-Johansson.



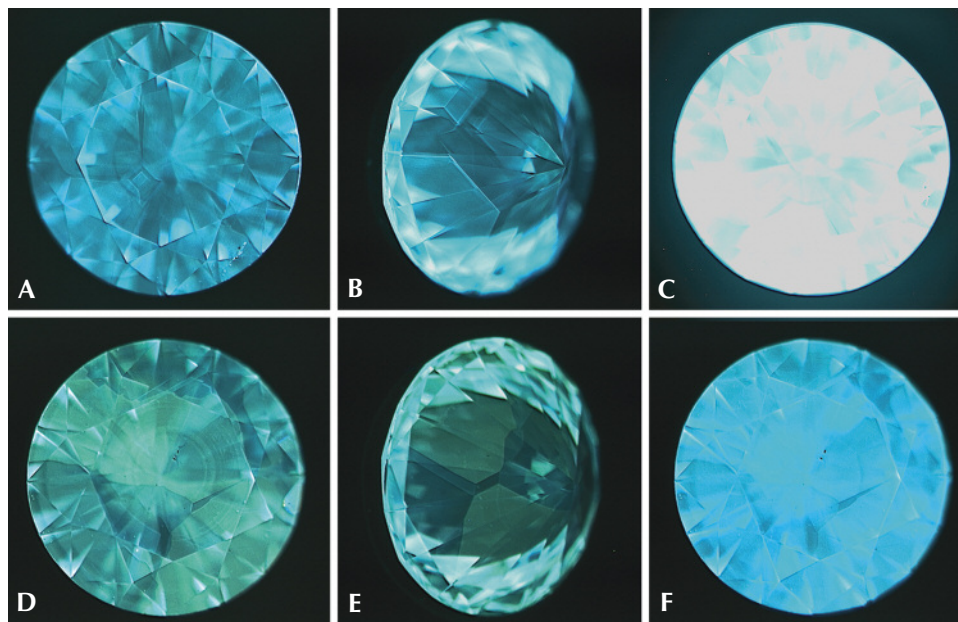


Figure 4. DiamondView images of samples B0124 (A–C) and B0148 (D–F). The fluorescence images (A, B, D, and E) show clear cuboctahedral patterns originating from their HPHT growth histories. The samples also displayed intense, long-lasting blue phosphorescence (C and F). These characteristics were observed for every AOTC sample. Images by Ulrika F.S. D’Haenens-Johansson.

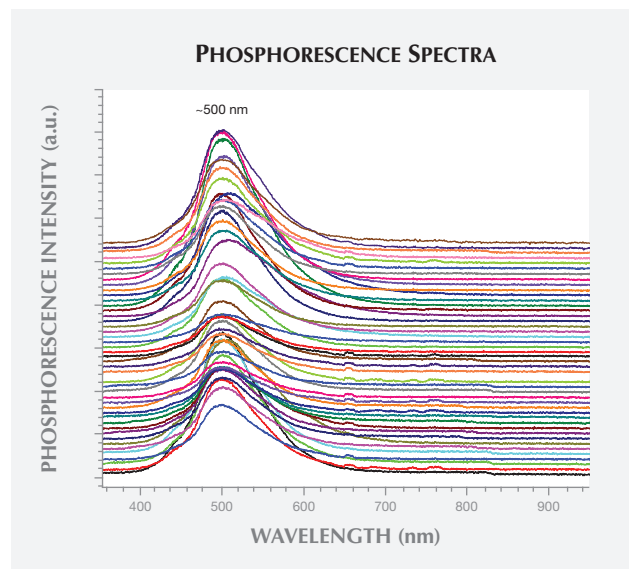
times the contrast between adjacent fluorescing sectors was weak, and viewing such samples along multiple directions greatly aided in distinguishing the patterns. The bulk fluorescence was either blue or green, and the samples had strong blue phosphorescence, as illustrated in figure 4.

The phosphorescence behavior of the non-melee synthetic diamonds was further investigated using the previously described custom-built phosphorescence spectrometer. With each of these samples, the broadband illumination of the spectrometer (215–2500 nm) induced a blue phosphorescent emission centered at approximately 500 nm, as shown in figure 5. No other phosphorescence peaks were detected. The emission band at 500 nm (2.48 eV) has been reported in type IIb HPHT synthetic diamonds, but it can also be seen in natural type IIb diamonds (Watanabe et al., 1997; Eaton-Magaña et al., 2008; Eaton-Magaña and Lu, 2011). The phosphorescence is thought to arise from donor-acceptor pair recombination between the boron acceptor and unknown donors, possibly nitrogen defects (Dean, 1965, 1973; Klein et al., 1995; Watanabe et al., 1997). Note that even the nominally type IIa samples (see the Infrared Absorption Spectroscopy section below) displayed phosphorescence, suggesting the presence of boron impurities in concentrations below the FTIR spectrometer’s detection limit.

Magnetism. All of the samples with SI₁–I₂ clarity grades were attracted to the rare-earth magnet, and most of the VS₂ samples were found to be weakly

magnetic (see table 1). Past studies of gem-quality HPHT synthetics have demonstrated the magnetism of their inclusions (Koivula and Fryer, 1984; Rossman and Kirschvink, 1984). Most of the inclusions originate from the solvent/catalyst, which is typically a ferromagnetic material such as Fe or its alloys. Thus, depending on the inclusion size and number, and the proximity and strength of the magnet, HPHT synthetic diamonds may show magnetic

Figure 5. The room-temperature phosphorescence spectra for the non-melee synthetic diamonds showed strong emission at approximately 500 nm. The spectra have been vertically translated for clarity.



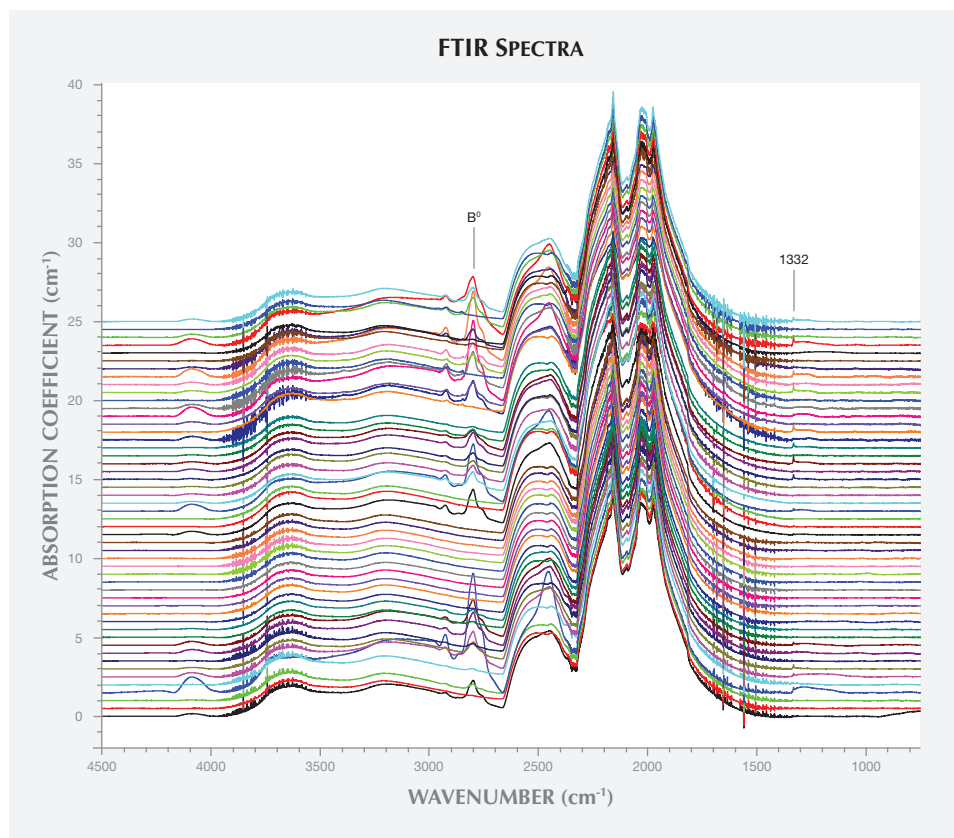


Figure 6. The FTIR spectra collected, translated vertically for clarity, revealed uncompensated boron absorption (B^0 at $\sim 2800\text{ cm}^{-1}$) and a weak peak at 1332 cm^{-1} . As a result, the AOTC samples were classified as mixed type IIa/IIb. The calculated bulk concentrations of B^0 are summarized in table 1.

attraction. It is extremely rare for the inclusions in a natural diamond to be attracted to a magnet (Koivula and Fryer, 1984), and CVD synthetics are not magnetic. Nevertheless, some diamonds, irrespective of their origin, demonstrate extremely weak magnetism due to surface contamination stemming from the cutting and polishing process. Careful cleaning will remove this effect (Rossman and Kirschvink, 1984). Magnetism is sometimes used to identify HPHT synthetic diamonds. If the synthetic diamonds do not contain significant inclusions, as was the case for 58% of the samples tested here, they will not be attracted to strong handheld magnets. Ultrasensitive equipment such as a superconducting quantum interference device (SQUID) may detect the magnetism of trace amounts of solvent/catalyst, but this is impractical for routine gemological investigations (Rossman and Kirschvink, 1984).

Electrical Conductivity. Electrical conductivity, occurring with white luminescence, was detected in some of the colored or lower-grade near-colorless samples, representing 17% of all the specimens tested (table 1). The conductivity measurements

were found to depend on the positioning of the electrical probes on the samples. Some of the samples reported as not conductive, therefore, may have actually had conducting regions that were not accessed due to geometry or volume conditions. Electrical conductivity can indicate the presence of boron in diamond. The presence of boron turns pure insulating diamond into a conductive material. The solubility of boron is growth-sector dependent, and previous studies of boron-containing diamonds have shown that concentrations can vary in orders of magnitude across different growth sectors of the same specimen, with the highest concentrations usually found in {111} sectors. Yet the sector with the highest boron concentration has also been reported to be strongly influenced by the degree of doping (Burns et al., 1990). Hence, it is not surprising that boron-containing HPHT synthetic diamonds have sector-dependent electrical conductivity (Rooney et al., 1993; Shigley et al., 1997).

Infrared Absorption Spectroscopy. Infrared absorption spectroscopy revealed that the AOTC synthetic diamonds were mixed type IIa/IIb, or pure type IIa (figure 6). All the toroid samples belonged to the lat-

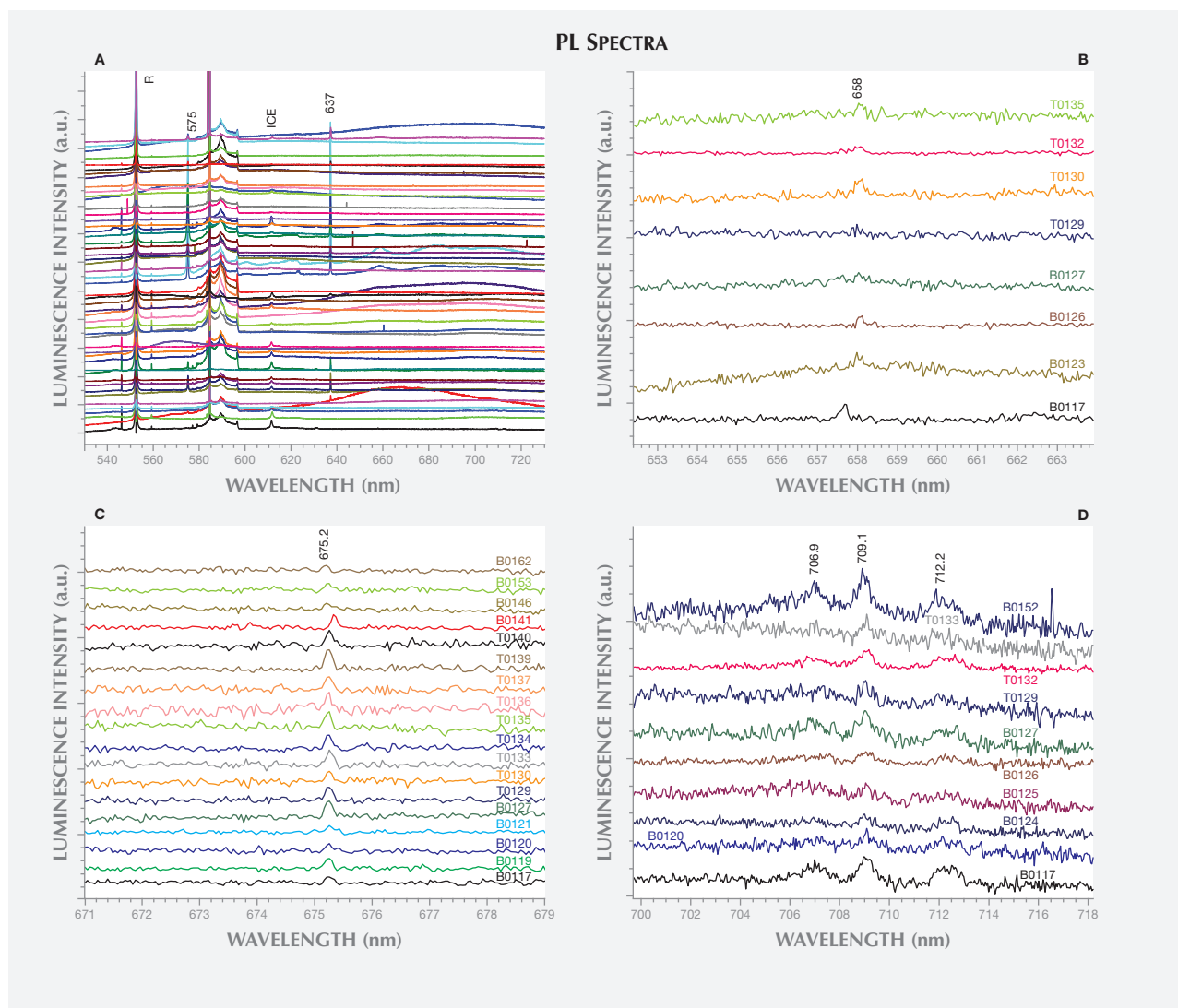


Figure 7. (A) PL spectra collected using 514.5 nm excitation were dominated by emission peaks from the NV⁰ (575 nm) and NV⁻ (637 nm) centers. “R” denotes the diamond Raman peak. In certain samples, the 514.5 nm laser also excited weak peaks at 658.0 nm (B), 675.2 nm (C), and a group of peaks at 706.9, 709.1, and 712.2 nm (D). Representative spectra are shown and have been translated vertically for clarity.

ter classification, producing FTIR spectra that lacked any clear impurity-related absorption. The spectra for 34 of the 40 BARS samples revealed the presence of uncompensated boron (approximately 2800 cm⁻¹). The faceting of the samples made it impossible to isolate specific growth sectors for individual FTIR absorption measurements. Although boron is not uniformly distributed throughout these multi-sector HPHT synthetic diamonds, bulk concentrations – [B⁰] averaged across the whole sample volume – were calculated using the integrated intensities of the 2800 cm⁻¹ feature, as described by Collins and Williams (1971) and Fisher et al. (2009). Regional boron concentrations will either be higher or lower

than the bulk values, tabulated in table 1, but the estimates allow for semi-quantitative comparison between samples.

A weak peak at 1332 cm⁻¹ was observed in 37 of the 40 BARS samples. Due to the high density of phonon states in this region, the identity of the 1332 cm⁻¹ peak is uncertain, though it has been observed in boron-doped diamonds and in synthetic diamond grown using nickel-containing solvent/catalyst (Collins et al., 1990a; Lawson and Kanda, 1993; Lawson et al., 1998). The FTIR spectrum for the positively charged state of the substitutional nitrogen center (N_s⁺) is characterized by a peak at 1332 cm⁻¹ and broad features at 1046 and 950 cm⁻¹ (Lawson et

al., 1998). As the latter two features were not observed in the AOTC samples' spectra, the 1332 cm^{-1} peak could not be attributed to this defect. Nor was the neutral charge state of substitutional nitrogen, N_s^0 , which produces a peak at 1344 cm^{-1} , detected in any of the spectra (Lawson et al., 1998).

Photoluminescence. PL spectroscopy at liquid-nitrogen temperatures revealed no single peak in all of the samples, even though several contained similar defects (identified by their characteristic emission peaks). Since it was possible to excite emission from certain defects using multiple lasers, they will be described here for the lasers that caused the most efficient excitation (figures 7–10). In general, the observed emission peaks were weak, and could only be detected when the power was high enough to saturate the diamond Raman peak.

Nitrogen-vacancy center ($\text{NV}^{0/-}$) concentrations were sufficiently high in 33 of the 52 total samples to produce detectable zero-phonon lines (ZPLs) at 575 nm (2.156 eV, neutral charge state) or 637 nm (1.945 eV, negative charge state) with 514.5, 532.0, or 488.0 nm laser excitations. In the 514.5 nm PL spectra, the 637 nm ZPL was more intense than the 575 nm ZPL for 64% of the samples showing these emissions (see figures 7A–D). These spectra also revealed weak unidentified peaks at 658.0 nm (1.884 eV) in 19 of the samples and at 675.2 nm (1.836 eV) in 9 samples (37% and 17%, respectively). Additionally, a set of faint emission lines at 706.9, 709.1, and 712.2 nm (1.754, 1.748, and 1.741 eV) was observed in 12 of the samples (23%). It is unknown whether these are related.

Overall, the synthetic diamonds grown by AOTC using toroid-press systems showed remarkably few (and weak) PL features, limited to those discussed above. The remaining laser excitation wavelengths did not induce any other defect-related emissions. Sample T0131 was exceptionally pure and did not have any detectable optical centers. Conversely, several of the diamonds synthesized using BARS-press technology showed additional ZPLs. Any other peaks discussed hereafter were only detected in this group of 40 BARS samples.

A weak peak at 503.2 nm (2.463 eV), possibly H3 (N-V-N^0), was detected in the 488.0 nm laser-excited PL spectra for 11 of the BARS samples (27.5%). Emission at this wavelength has previously been reported in both type IIa and IIb HPHT-grown synthetic diamonds (Dodge, 1986; Collins et al., 1990a; Sittas et al., 1996; Zaitsev, 2001).

As shown in figure 8, the negatively charged sili-

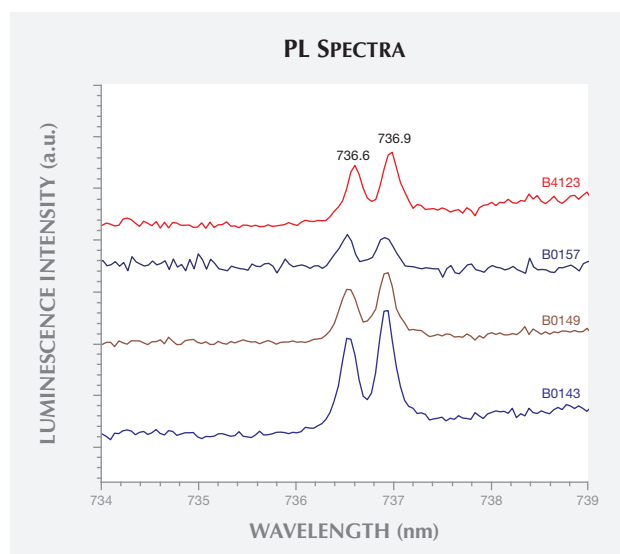


Figure 8. The SiV^- center, with emission peaks at 736.6 and 736.9 nm, was observed in the PL spectra for four samples using 632.8 nm laser excitation. Spectra have been translated vertically for clarity.

con split-vacancy defect, with a doublet ZPL at 736.6/736.9 nm (SiV^- , 1.683 eV), was clearly resolved in the 632.8 nm PL spectra for four samples (10%). This is surprising, as the presence of silicon (Si) is rarely reported in HPHT synthetic diamond. Intentional Si-doping occurred in the studies by Clark et al. (1995) and Sittas et al. (1996), where Si was added to the Fe, Fe-Ni, or Fe-Co solvent/catalyst mixture; the latter study also included Ti or Zr nitrogen getters. Si-doping by post-growth Si^+ implantation has also been reported (Collins et al., 1990b). To date, SiV^- has only been reported twice for faceted gem-quality HPHT synthetics, but it is unknown whether its presence was intentional or simply a byproduct of contamination (Moe and Wang, 2010; Wang and Moe, 2012).

A doublet at 882.6/884.3 nm (1.405/1.402 eV), excited using the 830.0 nm laser, was the most commonly observed ZPL, detected in 28 (70%) of the BARS samples (figure 9). This doublet, typically referred to as the 1.40 eV center, is frequently seen using absorption or PL spectroscopy in the $\{111\}$ growth sectors of HPHT synthetic diamonds produced using Ni-based solvent/catalysts (Collins et al., 1990a; Nazaré et al., 1991; Collins, 1992; Lawson and Kanda, 1993). Nazaré et al. were able to resolve the fine structure for the band and conducted uniaxial stress and Zeeman splitting measurements, conclusively determining that the defect responsible contains a single Ni atom (Davies et al., 1989). The splitting between the dominant 882.6 and 884.3 nm lines was found to rise with increasing linewidths,

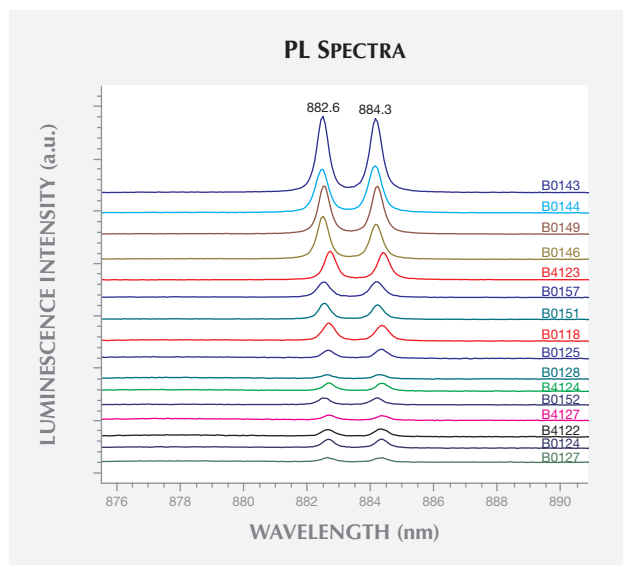
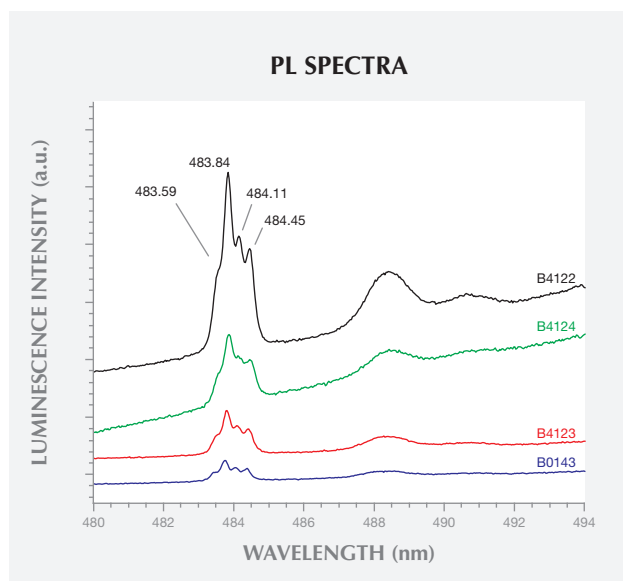


Figure 9. A Ni-related doublet at 882.6 and 884.3 nm was detected in most of the PL spectra (830.0 nm laser excitation) collected for the BARS samples. These representative spectra have been translated vertically for clarity.

which follow increasing strain levels. They hypothesized that the ZPL originates at an interstitial Ni⁺ atom distorted along a $\langle 111 \rangle$ direction. Although this is the most widely accepted model, it has not been

Figure 10. The 484 nm center, with peaks at 483.59, 483.84, 484.11, and 484.45 nm, was detected in the PL spectra (324.8 nm laser excitation) of 10 of the 40 BARS-grown samples. Only the most intense and clearly resolved spectra are presented here, translated vertically for clarity.



unambiguously confirmed (Yelissev and Kanda, 2007).

The 324.8 nm laser excitation PL spectra in figure 10 revealed the presence of a complex luminescence system, centered at about 484 nm in 10 of the 40 BARS samples. This band, referred to as the 484 nm or 2.56 eV center, is frequently observed in the absorption or PL (excitation wavelength <400 nm) spectra of Ni-doped HPHT synthetic diamonds. Like the 882.6/884.3 nm doublet, it is mainly restricted to $\{111\}$ growth sectors (Dean, 1965; Collins et al., 1990a; Collins, 1992). The band consists of peaks at 483.59, 483.84, 484.11, and 484.45 nm (2.564, 2.563, 2.561, and 2.559 eV) resulting from the splitting of the excited state. The 883.6/884.3 nm optical center was detected in the PL spectra for every AOTC sample that also contained the 484 nm center. The PL spectra acquired using the 457.0 and 532.0 nm laser excitations did not reveal any additional photoluminescent centers.

LA-ICP-MS. The LA-ICP-MS data collected on the surface-reaching inclusions of samples B0124 and T0130, thought to be remnants of the solvents/catalysts used during growth, provided clues to their growth capsule constituents. B0124 and T0130 were synthesized using BARS- and toroid-press technologies, respectively. The raw data are presented in figure 11, where the number of counts detected for certain elements were monitored as a function of time: before, during, and after the inclusion was vaporized by the laser. It is important to note that the sensitivity of LA-ICP-MS to different elements is not uniform, so these plots should not be compared for distinct elements. Conventionally, quantitative concentration analysis can be achieved by comparing the intensity of the detected counts for each element with that for a reference sample with known, calibrated element concentrations. The large variance (at times multiple orders of magnitude) in the concentration of different elements between the inclusions and the reference samples introduced uncertainties significant enough that quantitative analysis of relative concentrations was not deemed suitable. Nevertheless, the LA-ICP-MS data proved reliable in determining the presence of certain elements in the inclusion.

The metallic inclusions in samples B0124 and T0130 clearly contained Fe and Zr, and a weak signal was detected from Cu. Sample B0124's inclusion also contained Hf and Co, while T0130 showed considerable levels of Al. Ni, whose presence was identified by the PL data for B0124, was not detected in either

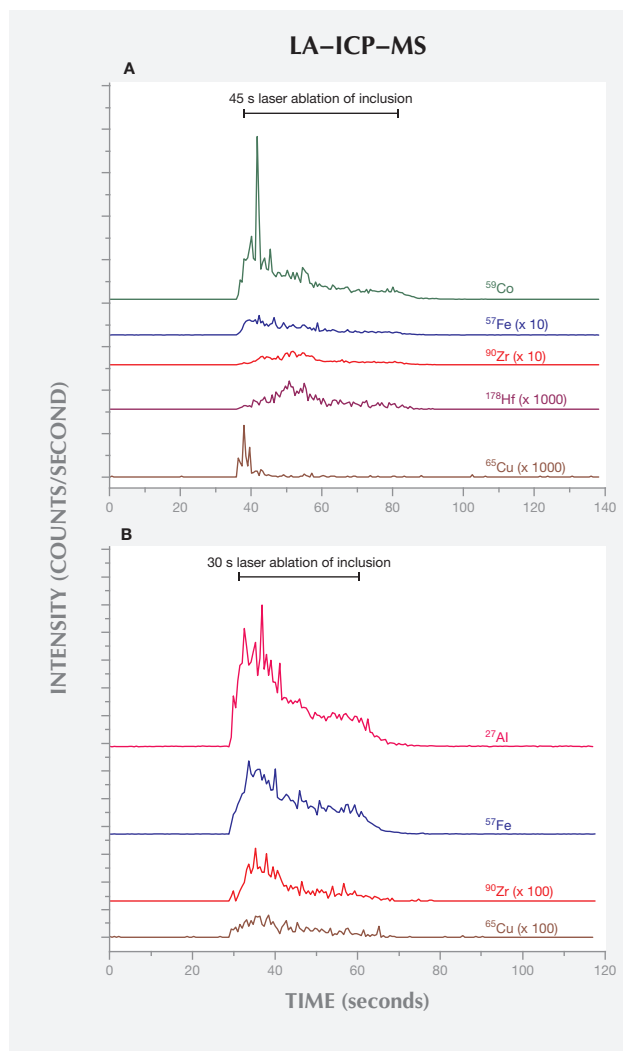


Figure 11. LA-ICP-MS data for the inclusions in samples B0124 (A) and T0130 (B), which were grown using BARS- and toroid-press technologies, respectively. The traces have been scaled and vertically translated for clarity.

sample. This is likely a result of relatively poor detection limits for Ni with LA-ICP-MS instruments such as the X-Series II, which use skimmer cones made of Ni. Fe and Co are commonly used in the solvent/catalyst mixtures for HPHT synthetic diamond growth. Al, Zr, and Hf have been previously used as nitrogen getters for HPHT diamond synthesis, while Cu can be used to reduce the formation of carbides such as ZrC (Strong and Chrenko, 1971; Burns et al., 1990; Sumiya and Satoh, 1996; Sumiya et al., 1996).

DISCUSSION

Improvements by AOTC in Gem-Quality HPHT Synthetic Diamonds. The growth of colorless HPHT

synthetic diamonds for faceting on a commercial scale has proven extremely complex. The primary challenges have been to exclude readily incorporated nitrogen impurities, while simultaneously achieving acceptable growth rates and minimizing the incorporation of the solvent/catalyst melt, which forms unattractive inclusions. Sophisticated presses with accurate long-term temperature and pressure controls are necessary, in conjunction with a carefully selected combination of carbon source, nitrogen getter, and solvent/catalyst. Previous efforts to manufacture similarly colored material by this method have been limited by technological or economic constraints; successful fabrication has been done primarily for research purposes or niche industrial applications (Crowningshield, 1971; Rooney et al., 1993; Shigley et al., 1993, 1997; Sumiya and Satoh, 1996; Sumiya et al., 2002).

The overall quality of the AOTC samples was remarkably high, with 77% of the suite assigned colorless to near-colorless grades. Furthermore, the specimens reached sizes that are popular with the jewelry consumer, with the largest sample weighing 0.80 ct. Clarity, which ranged from IF to I₂, was typically affected by the presence of dark inclusions originating from the solvent/catalyst melt. The clarity grades did not strictly correlate with size or color, though the melee-size specimens were generally of higher clarity. Overall, the clarities seen in these colorless and near-colorless HPHT synthetics are considerably better than most previous products. This combination of color, size, and clarity makes the AOTC products, on first inspection, comparable to natural and CVD synthetic diamonds on the market.

Characterization using PL, FTIR absorption, and LA-ICP-MS has provided a body of data that allows us to speculate about the identity of some key chemical components present during the HPHT synthesis of the samples and comment on the resulting gemological characteristics. FTIR data demonstrated that most of the BARS-press synthetics contained extremely low levels of boron impurities and no detectable levels of isolated nitrogen defects. The low concentration of nitrogen defects indicates the use of a nitrogen getter during growth. The yellow color often associated with HPHT synthetic diamonds arises from typically high concentrations of neutrally charged substitutional nitrogen. Neutral substitutional nitrogen was not detected in the AOTC samples, which explains the absence of a yellow hue. On the other hand, the neutral boron that was detected can introduce a blue hue. The color ultimately

achieved is affected by not only the concentration of the different color-producing defects, but also by the diamond's volume and faceting arrangement. Overall, synthetic diamonds with low boron concentrations were likely to appear colorless to near-colorless, while the samples with higher boron concentrations tended to show enough saturation of blue color to be graded using the fancy color scale. In all likelihood, a combination of color-producing defects was responsible for the non-blue colors observed in a small subset of the samples.

PL spectroscopy revealed that 70% of the samples grown using BARS presses contained Ni-related impurities. Ni is frequently used in the solvent/catalyst mixture, as it reduces the temperature and pressure conditions needed for diamond synthesis. Conversely, there was no evidence for the incorporation of Ni in any of the samples produced by toroid presses. This suggests the use of a different solvent/catalyst mixture for the two press types. Unfortunately, PL-active defects produced by Fe or Co, elements that are often constituents of the solvent/catalyst, have not yet been identified in as-grown HPHT synthetic diamond. While a few Co-related PL features have been reported in annealed synthetic diamonds, they were limited to samples with significant nitrogen contamination (Lawson et al., 1996). The AOTC samples had nitrogen concentrations below the FTIR spectrometer's detection limit and reportedly have not undergone post-growth treatment (D.NEA, 2014b). Hence, PL cannot be used to confirm or rule out the presence of Fe or Co. It is unknown whether the presence of SiV⁻ in the PL spectra for four of the BARS-press samples arose from intentional Si-doping, but the low concentration suggests that it resulted from contamination.

Notably, the samples produced by toroid presses showed uncommonly faint and limited features in their PL spectra. This result, combined with the absence of detectable defect-related absorption in their FTIR spectra, suggests that AOTC has exerted more control over impurity incorporation in its toroid-press production. These samples, however, were more likely to contain significant inclusions from the solvent/catalyst melt.

LA-ICP-MS analysis of inclusions in samples grown using the two different press types revealed additional information. Although only two samples were analyzed, and caution must be taken when extrapolating the results to AOTC's entire commercial production, the gemological and spectroscopic properties were consistent with the remaining samples

from the two press types. The inclusions' chemical composition provides strong indications about the solvent catalysts and nitrogen getters used during synthesis in the two different presses. Our chemical data suggest that the BARS press employed some combination of Fe, Co, and Ni in the solvent catalyst; Zr and Hf as nitrogen getters; and Cu to reduce inclusions. For the toroid press, we saw evidence of the addition of Zr and Al as nitrogen getters and Cu to reduce inclusions, but it remains unclear what other elements besides Fe constituted the solvent catalyst. If present, Co and Ni were likely much lower in concentration in the toroid growth process. Additional analysis is necessary to constrain this further.

Identification Features. Similar to previous reports on HPHT synthetic diamond from other manufacturers, certain visual characteristics can be used to characterize the AOTC samples as HPHT synthetic, although advanced testing is necessary for conclusive identification. Due to the high color grades of the AOTC product, visual inspection did not reveal patterned color zoning arising from their cuboctahedral growth morphology. Under magnification, unusual elongated, dark metallic solvent/catalyst inclusions, similar to those often seen in other HPHT synthetic diamonds, were observed in some samples. If heavily included, the AOTC synthetics were also attracted to a strong magnet, confirming the presence of ferrous material not associated with natural diamonds. The shape and metallic appearance of the inclusions are an extremely rare combination in natural diamonds, and should therefore arouse suspicion (Sobolev et al., 1981). When viewed between crossed polarizers, AOTC's HPHT synthetics also showed remarkably low levels of strain without a discernible pattern. This is in contrast to natural diamonds, which typically show cross-hatched "tatami," banded, or mottled strain patterns.

Illumination with a standard gemological UV lamp produced a yellowish green fluorescence and phosphorescence to short-wave UV, while the samples were inert to long-wave UV. The stronger response to short-wave UV is the opposite of the reaction observed for most natural diamonds (Shigley et al., 1993). The intense, long-lasting phosphorescence induced in some of the AOTC synthetics is seldom observed in natural diamonds and should alert the gemologist to the need for more detailed analysis. Fancy-color HPHT synthetic diamonds often display a fluorescence zoning arising from the variation in the uptake of impurities for the different growth sectors. In this study, the contrast

was too low to be detected using a handheld UV lamp. Only the high-energy UV excitation and magnification-enabled imaging of the DiamondView instrument revealed the cuboctahedral growth patterns characteristic of HPHT synthetics.

FTIR spectra characterized the AOTC synthetic diamonds as type IIa/IIb, without any features exclusive to HPHT synthetics. Since the majority of natural near-colorless diamonds are type IaA, however, all type IIa or IIb samples should be treated with caution and subjected to additional testing. PL spectroscopy was able to demonstrate the presence of Ni-related impurities in most of the BARS-press samples, which displayed distinctive lines at 882.6/884.3 nm and a band of four lines centered at about 484.0 nm. It is important to note that Ni-related defects are rarely detected in natural diamonds (Nobel et al., 1998; Chalain, 2003; unpublished GIA research), and their presence should immediately raise suspicion. Significantly, these features were absent in the PL spectra of AOTC's toroid-press synthetic diamonds.

Other useful peaks at 658.0, 675.2, 706.9, 709.1, and 712.2 nm were seen in some samples, from both BARS- and toroid-type presses. These peaks have not previously been reported and are thus promising for identification purposes. The detection of the SiV optical center at 736.6/736.9 nm in four AOTC samples, in addition to a number of natural and HPHT-

grown synthetic diamonds (Breeding and Wang, 2008; Moe and Wang, 2010; Wang and Moe, 2012), emphasizes that this feature should not be considered proof of CVD synthesis. Overall, the high purity levels of the AOTC synthetics resulted in PL features that were usually much weaker than the diamond Raman peak, requiring a high-sensitivity spectrometer for detection.

CONCLUSION

The high quality and excellent colors achieved by AOTC's latest HPHT synthetic diamonds represent an important milestone, as well as a new challenge for identification. No longer can a gemologist assume that colorless HPHT synthetics will contain abundant metallic inclusions. Analysis of a suite of 52 specimens from this manufacturer has underscored the fact that conclusive identification of synthetics cannot be made simply using a single gemological or spectroscopic method. Fortunately, the tools available to the average gemologist will enable recognition of features that may imply a synthetic origin, and alert them to the need for additional advanced testing by a gemological laboratory. By combining a variety of gemological, spectroscopic, and fluorescence imaging techniques, all of the AOTC samples could be unequivocally recognized as HPHT synthetic diamonds.

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HUNTING FOR “JEDI” SPINELS IN MOGOK

Vincent Pardieu



Miners collect spinels from gravel at the end of a long day at Man Sin. Photo by Vincent Pardieu, © GIA.

In the spring of 2001, I was studying gemology in Yangon, Myanmar, thanks to the support of U Kyaw Thaung, a Burmese merchant from Mogok. It was a great period in my early life as a gemologist, living for several months with a Burmese gem trading family in an exotic country. One day, my host was visited by Hemi Englisher, a Bangkok-based gem dealer. When they finished business, Hemi asked me to join them, as he wanted to show me something special (figures 1 and 2). In his hand was something I had never seen: stunning little gems with a bright

neon pinkish red color, convincing me that spinels could equal rubies in beauty.

I asked if they were from Mogok, and the answer was equally surprising: No. They were from Namya, a ruby and spinel deposit located east of the jade mine at Hpakant in the Kachin state of Myanmar, where a gem rush had occurred in December 2000. I could hardly imagine then that a few months later I would follow Hemi to Namya for my very first field expedition. That adventure was truly a life-changing event (figure 3).

Over time, I started to have the feeling that these incredible little gems were somewhat lucky for me. In the spring of 2002, I landed my first job in the gem trade thanks to them. Henry Ho, a gem merchant from Bangkok and a spinel connoisseur, hired me with a simple mission: to find a bright 10 ct spinel

See end of article for About the Author and Acknowledgments.

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Figure 1. Fraicheur et delices (Cool and delicious): These bright neon red spinel crystals are from Man Sin, Mogok. Photo by Vincent Pardieu, © GIA.



Figure 2. A parcel of fine spinel crystals from Namya similar to those the author saw in Yangon in 2001. Because Namya is a secondary deposit, most of its gems are more tumbled than typical stones from Mogok. Photo by Vincent Pardieu, © GIA.

from Namya. We spent days together in Myanmar looking at gems. It was very different from my experience as a gemology student, as we were not focusing on gem identification but on quality and potential value. I learned that the typical downfall of an otherwise fine spinel was a dark tone, or “dark side,” within the gem. At the time, the Hollywood blockbuster *Star Wars: Episode II—Attack of the Clones* was in theaters, and my motto became: “The

Force is strong in spinel, but beware the dark side of the Force.” Thus, we took to calling these glowing hot pink gems “Jedi” spinels, as they were untouched by the “dark side” (figure 4).

Like many, I believed for years that such “Jedi” spinels could only be found at Namya. Yet I was intrigued when some Burmese friends told me several times between 2001 and 2005 that such specimens were reportedly found from time to time around

Figure 3. Left: U Kyaw Thaung, the author, and Hemi Englisher in Yangon in February 2001, the day Hemi introduced the author to his first Namya spinels. Photo by Zin Mee Mee Lwin. Right: On the way to the Namya ruby and spinel mining area in 2001, the author enjoys his very first field expedition. As the deposit was located in a jungle-covered swamp, expedition leaders Hemi Englisher and Ted Themelis traveled by elephant while the author and the native guides walked in the swamp. Photo by an anonymous Burmese soldier, courtesy of the author.





Figure 4. Hai An Nguyen Bui looks into a bright neon red spinel crystal, reportedly from Namya, while visiting Yangon in December 2006. Note the tumbled aspect typical of spinel from secondary deposits such as Namya. Photo by Vincent Pardieu/AIGS.

Mogok. These stones were usually sold as Namya spinels to get better prices. Was it just a rumor? Finding out proved to be difficult. The so-called Namya spinels were incredibly rare and in very high demand.



Figure 5. These parcels consist of bright neon red spinels from Man Sin (left) and classic red Mogok spinels (right). Note the unmistakable difference in tone and saturation between the two parcels. Photo by Vincent Pardieu, © GIA.

Despite my efforts, I was unable to find any evidence that Mogok had produced any spinel as bright as those from Namya (figures 5 and 6). Even if the rumors were true, calling them “Namya” spinel might prove controversial. (Consider the longstanding dispute in the gem trade over the origin-related term “Paraíba” to describe exceptionally vivid tourmaline, not only from Brazil, but also Mozambique and Nigeria.) Besides, “Jedi” spinel was fun and had a nice sound.

RED SPINEL AND ITS SOURCES

Historically, most red spinel comes from four remote places (Pardieu, 2008). From oldest to newest source, they are:



Figure 6. Classic rough and faceted red spinels from Mogok. The faceted stone, a fine red spinel weighing more than 5 ct, was purchased in the 1940s by Dr. Edward Gübelin. The crystals in the background are from the author’s collection. Photo by Vincent Pardieu, courtesy of Gübelin Gem Lab.

- 1) Badakhshan: This region is located between Afghanistan and Tajikistan, along the famed Silk Road. It has been a source of spinel since about the 10th century. According to locals, several deposits exist on both sides of the border, but the most famous mining site is near the Kul-i-Lal village on the Tajik side (Bowersox and Chamberlin, 1995; Bowersox, 2005; Hughes, 2006; Pardieu, 2006).
- 2) Myanmar (formerly Burma): Spinel has been found in both the Mogok Valley and the Namya area (Iyer, 1953; Gübelin, 1965; Keller, 1983; Kane and Kammerling, 1992; Themelis, 2000; Schlüssel, 2002; Themelis, 2008).
- 3) Vietnam: Red and blue spinel, along with ruby, was discovered in the Luc Yen district of northern Vietnam in 1988 (Long, 2013).
- 4) Tanzania: Red spinel was discovered near Mahenge and in the Uluguru Mountains of the Morogoro province in the late 1980s, and around Tunduru after 1994. The deposit near Mahenge became famous after the discovery of giant spinel crystals (up to 54 kg) during the summer of 2007 (Keller, 1992; Pardieu, 2007; Weinberg, 2007; Hughes, 2011).

Over the past 12 years, I have collected samples from all these spinel deposits—as well as others in Pakistan, Kenya, Sri Lanka, and Madagascar—but none could match the saturation and brightness of the “Jedi” gems from Namya until very recently.

In 2011, Lou-Pierre Bryl, a gem merchant who travels regularly to Myanmar, repeated a rumor about a new spinel deposit in Mogok with material as bright as that from Namya. As Mogok was still not open to foreigners, we could not travel there to confirm the rumor.

In June 2013, Mogok was once again accessible to the outside world. I was unable to travel and asked Lou-Pierre, who was headed there, to inquire about this deposit. In August 2013, after three expeditions, Lou-Pierre confirmed the existence of a new spinel source in Man Sin. It was about a kilometer from Pyant Gyi and Pein Pyit (see figure 16), two areas known for producing beautiful spinels in the early 2000s, including some stunning “Star of David” macle crystals (figure 7). We decided to visit Mogok in September 2013, with a field trip to Man Sin as our main objective.

Any successful field expedition requires a good vehicle, the right permits, and the right local contacts. Within a few days, we contacted Jean-Yves



Figure 7. This fine “Star of David” spinel crystal is a macle, reportedly from the Pein Pyit/Pyant Gyi area east of Mogok, which was known for producing such crystals between 2000 and 2005. No processing, slicing, or polishing was performed on this specimen; it is 100% natural. Photo by Vincent Pardieu, © GIA.

Branchard from Ananda Tours in Yangon to help us with permits and logistics. We also made arrangements with Jordan, who had been my driver, assistant, and translator during my previous time in Myanmar as a spinel buyer.

AN INTRODUCTION TO MOGOK

For gemologists and gem connoisseurs, Mogok (figure 8) must be experienced at least once in a lifetime. Gem mining likely began there more than a thou-

Figure 8. A classic view of Mogok town, dominated by the Chan Thar Gyi Pagoda (left) and arranged around its lake, which was created from a gem mine worked during British colonial times. Photo by Vincent Pardieu, © GIA.





Figure 9. A Shan woman studies a parcel of spinel crystals at a gem market in Mogok. Photo by Vincent Pardieu, © GIA.

sand years ago, and no other area on Earth has produced so many exceptional rubies, sapphires, spinels, or peridots (Themelis, 2000; Schlüssel, 2002).

Mogok is the ultimate ruby land. Imagine a group of beautiful green valleys dominated by jungle-covered mountains, many of them topped by delicate pagodas. The twin cities of Mogok and Kyatpyin and the surrounding villages are still mainly comprised of wooden houses, giving them a quiet, romantic aspect.

Far removed from the modern ways of doing business using cell phones, airplanes, cars, and air-conditioned offices, the people of Mogok can be seen each day at the colorful gem and vegetable markets. Visitors will enjoy not only the diversity of gems produced around Mogok but also the diversity of its population: the Shan, Burmese, Nepalese, and Lissu are the main players in a rich and fascinating gem culture (figure 9).

FRAICHEUR ET DELICES...

For years, I referred to Burma as another world, as going there was like leaving the modern world to enter a place where time was of no concern. Even

with modernity slowly making its way into Myanmar, the visitor spending a few days in Mogok still enjoys an experience truly from another time. In Mogok, I am reminded of Julius, a character from Joseph Kessel's novel *La vallée des rubis* (1955), who would say the words *fraicheur et delices* ("Cool and delicious") each time he looked at a fine gem or visited somewhere particularly interesting. Reading that novel as a child sparked my interest in Burma and gemstones. Each time I visit a place like Mogok and have the chance to encounter true beauty, these words come immediately to mind as a perfect way to describe this unique feeling and experience.

ARRIVING IN MOGOK

On September 19, 2013, Lou-Pierre and I took a morning flight from Bangkok to Mandalay. After exchanging some cash into Burmese kyat, we left for Mogok, using the new road past May Mio (also known as Pyin Oo Lwin) through the western part of Shan state. We reached Mogok around noon the next day.

After a typically quick Burmese lunch, we left for the Pan Shan gem market (figure 10) to meet U Ko James, a merchant specializing in spinel. I first met him in 2003, when he was on the rise. Nowadays he is an important man, and in Mogok many call him the "Spinel King." Mogok time passes slowly, but things went very quickly that day, as within a few minutes one of Ko James' contacts arrived with two small plastic baggies.

Fraicheur et delices, indeed. I had in my hand three stunning spinel crystals (figure 11), with deep, pure, highly saturated color and no dark tone. These were true "Jedi" spinels. But there was something more to the story: Unlike the rounded spinels I used to see from Namya, a secondary deposit, these were fine euhedral crystals with highly transparent faces. They had an incredible combination of crystal shape, color, and transparency. Forgive me for saying it, but they looked as good as synthetic spinel crystals. Gazing at them, I recalled the words of the great French merchant and explorer Jean-Baptiste Tavernier (1676) to describe exceptional transparency and crystallization of a gem: "fine water." These were perfect examples of "fine water" spinel crystals (figure 12).

On September 21, we started our day visiting the Cinema morning gem market. This market is usually stocked with low-quality stones, but it is still an interesting place to find out which deposits are active and what they are producing.



Figure 10. View of the Pan Shan afternoon gem market, where hundreds of traders gather each day. Photo by Vincent Pardieu, © GIA.

Next, we visited U Ko James (figure 13) at his home to talk about Mogok and see some special gems he was not willing to show at the market. He pointed out that between 2000 and 2005, the most

Figure 11. Lou-Pierre Bryl (right) shows what this expedition was all about: “Jedi” spinels from Man Sin. Photo by Vincent Pardieu, © GIA.



active spinel-mining area in Mogok was around Pyan Gyi and Pein Pyit. During that period, most of the bright neon material on the market came from the Namya area in Kachin state. But he confirmed that Mogok was also sporadically producing such gems. The area around Sakangyi probably supplied the best stones, followed by Shuant Pan. In 2006, some bright, highly fluorescent neon spinels emerged from Man Sin, and production peaked around 2009 with the discovery of a large pocket. Since then, production has been more sporadic. Overall, the stones from Man Sin were redder than those from Namya, which tend to be hot pink.

U Ko James said the largest fine spinel he had observed from Man Sin was a beautiful 35 ct rough stone, but it was not clean. Fine large gems were, and still are, extremely rare. Since 2006, he has seen

Figure 12. Details of the three fabulous spinel crystals seen at the gem market in Mogok. Photo by Vincent Pardieu, © GIA.





Figure 13. Going to the field is about three things: a place, its people, and its gems. U Ko James, known locally as the “Spinel King,” displays some incredible parcels of bright red stones from Mogok. Photo by Vincent Pardieu, © GIA.

fewer than 10 fine rough stones over 20 ct (with “Jedi”-type color and clarity), and fewer than 100 stones over 10 ct. Most of the output consisted of

Figure 14. These fine, clean spinels are from Mogok. The neon pink one (left), just over 7 ct, was fluorescent and difficult to photograph. It is believed to have been mined at Man Sin. The 8 ct stone (right) was especially stunning. Photo by Vincent Pardieu, © GIA.



Figure 15. A selection of bright neon spinel crystals from Man Sin (left and center), alongside two spinel crystals from Namya (right). Note how the crystals from these two origins have a similar brightness; however, the two crystals from Namya are rounded, while those from Man Sin are sharp and well-formed. The larger crystals are about 1 ct each. Photo by Vincent Pardieu, © GIA.

stones weighing less than 1 ct. He added that very few fine faceted gems over 10 ct have come from Man Sin. Fortunately, we were able to see two fine specimens (figure 14). One weighed slightly more than 8 ct (reportedly from Man Sin, though U Ko James could not guarantee its origin); the other, a bit more pink, was a 7 ct stone that he said was from Man Sin. Perhaps my opinion was influenced by my enjoyment of Mogok, but when these stones appeared before my eyes, they were the most beautiful spinels I had ever seen.

While spinel from Namya once fetched premium prices, U Ko James told us that Man Sin’s gems now draw the highest prices in the Burmese market. This is not based on reputation, as Man Sin still does not have Namya’s name recognition, but on these fine spinels being redder and larger, with the same neon brightness due to a similar high saturation associated with a minimal tone (figure 15).

At the end of that wonderfully educational morning, we were able to buy a few interesting spinel samples, reportedly from both Man Sin and Namya, from U Ko James. After our purchase, we left for Man Sin.

A VISIT TO THE MAN SIN SPINEL MINES

Man Sin, which means “clear mirror” in Burmese, is a karstic area, meaning that the landscape has been formed by the dissolution of soluble rocks such as limestone and dolomite. It is located at 22°58’18”N and 96°32’32”E (figure 16), surrounded by Ta Yan Show to the southwest, Pyan Gyi/Pein Pyit to the

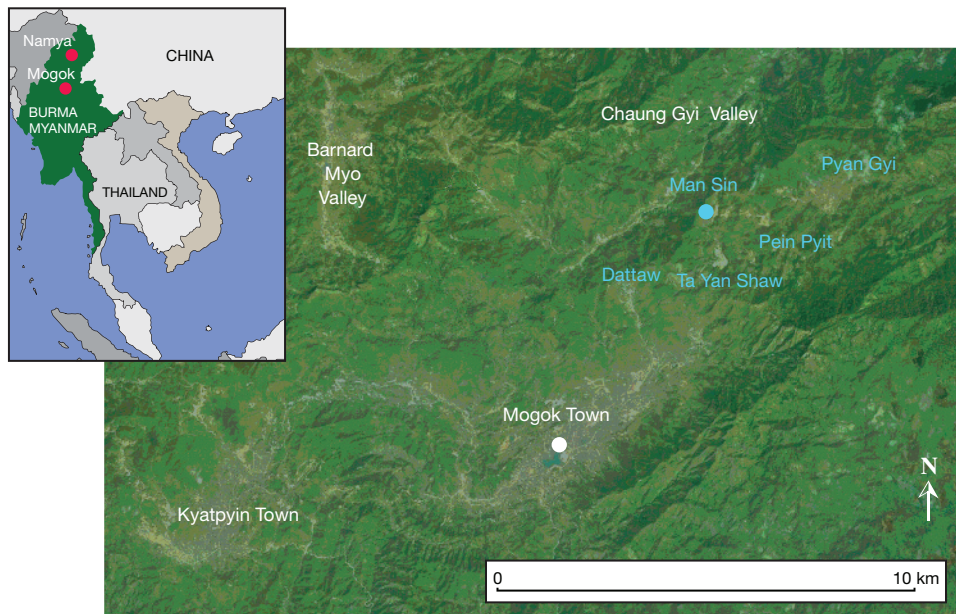


Figure 16. This map of Mogok (modified from Google Earth) shows the Man Sin spinel mining area, surrounded by other famous gem sites such as Dattaw, Ta Yan Shaw, Pein Pyit, and Pyan Gyi.

east, and the Chaung Gyi Valley to the north. In Man Sin, Nepalese farmers grow vegetables, mustard, and wheat. When we visited, three mining areas were producing mainly rubies. Another site, worked by two brothers of Nepalese origin named U Si Tu and U Kyaw Thu, yielded spinel (figure 17).

Interestingly, the miners at Man Sin are not searching for *byon*, the Burmese term for the gem-rich gravels found around Mogok and Kyatpyin. In the narrow

V-shaped valley at Man Sin, the erosion process is recent, and spinel can be found anywhere in the soil. The miners simply wash everything they collect from top to bottom. I witnessed a similar type of deposit at the spinel mines near Mahenge in Tanzania, which are also located in a narrow karstic valley.

At Man Sin, the operation managed by the two Nepalese brothers is relatively small. About 20 people operate an excavator, a few water cannons, and



Figure 17. Spinel mining at Man Sin. The gems are unearthed by washing the ground in this karst-type geologic environment. On the other side of the hill, to the north, is the Chaung Gyi Valley. Photo by Vincent Pardieu, © GIA.

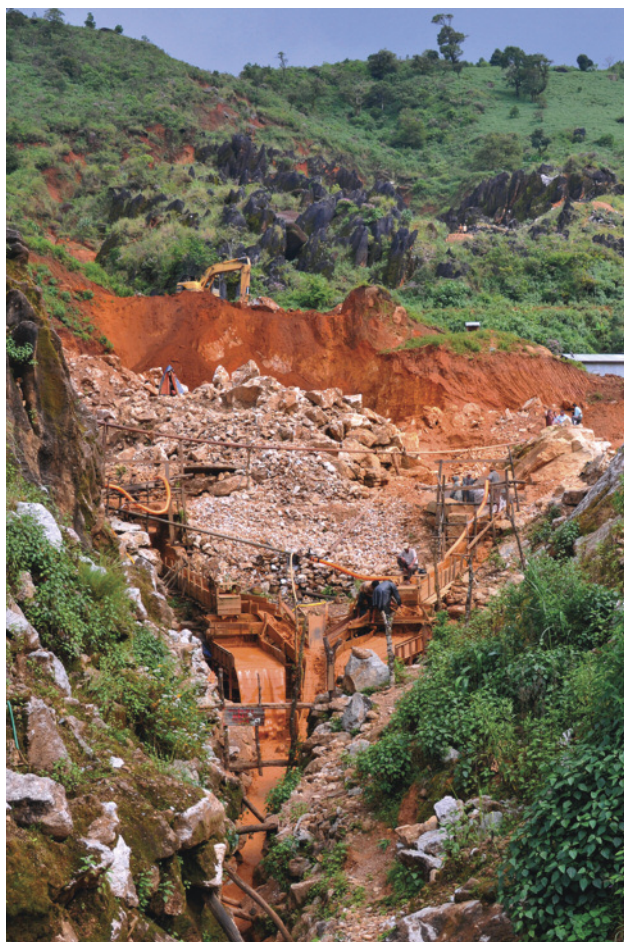


Figure 18. Overview of the spinel mining operation at Man Sin, where 20 workers operate an excavator, water cannons, and two washing plants. Photo by Vincent Pardieu, © GIA.

two washing plants (see lead photo and figure 18). Some of the workers earn a salary, while others own a share of the mine. The brothers, who told us they started production about 12 years ago, must renew their mining license every three years through Myanmar Gem Enterprises (MGE). They found their first pocket of “Jedi” spinels in 2009. Their first significant production consisted of several kilos of small, bright red crystals in their jig. It was an incredible sight, as the entire jig was reportedly filled with “wet” fluorescent red crystals glowing like embers in the evening light. Since then, output has been irregular. Sometimes a week passes by without any good yield, but then the next day they can find one or two kilos of fine gems in their jig. As they put it, “You may find a thousand fine gems, or nothing at all.”

We also learned that only the northern part of this mine, close to the Chaung Gyi Valley, regularly produces fine spinel of the “Jedi” kind; the southern

area, close to the other operations in Man Sin, primarily yields ruby. In the eastern part, most of the spinels are reportedly of the classic red type found in Mogok, possessing a higher, darker tone than “Jedi” spinels (figure 19).

While observing operations that day, we saw that the miners were able to find a few bright “Jedi”-type spinel crystals associated with some small rubies, some green tourmaline, and many spinels featuring a dark purple core and a shallow blue surface. As all the shareholders were not present during our visit, we could not immediately acquire any of the fine spinel mined that day. To obtain samples, we were told to visit U Kyaw Thu and his family at their home the next day. We did obtain a few small, bright red spinels for the GIA reference collection from a kanase woman who was mining the rejects under the jig.

That night we returned to Mogok with the miners. The following day, we visited the brothers and their family (figure 20). There we had tea and studied

Figure 19. U Si Thu examines a spinel crystal he found at Man Sin. If the stone appears somewhat ordinary at first sight, even experienced spinel miners know that such pockets can also host high-value gem material. Photo by Vincent Pardieu, © GIA.





Figure 20. There are no gems without gem people. U Si Thu (right) and his parents show some fine spinels from the mine at Man Sin. Photo by Vincent Pardieu, © GIA.

some of the stones from their recent production, acquiring additional samples for the GIA reference collection. Not surprisingly, most of the stones we saw either at the mine, from the miners' stock, at the gem market, or from U Ko James' stock barely showed evidence of weathering. This is very different from the spinel crystals found in Namya, which are usually quite tumbled. We were also told that no one has found "Jedi" spinel in matrix. Regarding size and quality, the miners said the best stones they ever found were two perfect crystals of about 5 ct each, much smaller than what U Ko James reported (figure 21). I often remember the words of Dr. Saw Naung

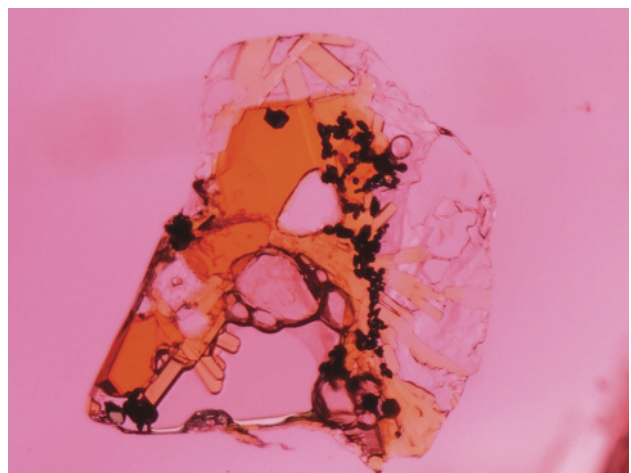
Figure 21. Fine "Jedi" spinels from Man Sin. The seven faceted stones on the left have a total weight of 12.9 ct, while the two clean crystals weigh 3.9 and 3.3 ct. Photo by Vincent Pardieu, © GIA.



Oo, a Burmese miner who helped me during my different visits to Mogok between 2001 and 2004: He once told me that in Mogok, the miners keep secrets while the traders tell stories. Hearsay is one of the main challenges faced by gemologists—and not only in the field. Indeed, lab gemologists should rely more on their eyes than their ears.

Upon my return to Bangkok, the team at GIA's lab studied the samples. Notably, the stones from these three different sources shared some distinguishing features not often found in spinel from other sources, such as multiphase orange inclusions (figure 22) where diaspore, pyrite, sulfur, and

Figure 22. The samples obtained during the trip to Man Sin exhibited characteristics, such as this orange multiphase inclusion, that are not normally associated with spinel from other sources. Photomicrograph by Jonathan Muyal, magnified 100x.



dolomite (as identified by Raman) were found to be associated together. Furthermore, chemical analysis yielded two intriguing discoveries. First, the stones that were collected from the kanase woman at the mine, from the private home of the Nepalese brothers, and from U Ko James had a similar chemical composition at the trace-element level. This “fingerprint” was quite different from the samples obtained during field expeditions to any other spinel deposit around the world. This indicates that chemical composition may become a very useful tool for determining the origin of spinel. Second, the “Jedi” spinel from both Man Sin and Namya have very low iron content when compared with spinel from Mogok, Vietnam, Tanzania, and Tajikistan and with “non-Jedi” spinel from other mining sites in Mogok. In both red and blue spinel, the high tone seems to be explained by the presence of iron, while red spinel owes its color to the presence of chromium.

The separation of Man Sin spinel from those produced at Namya or other sites may be aided by the data collection we are currently developing from analyses of data collected from stones at other deposits. Determining what is actually coming out of Man Sin in terms of size and quality will not be easy, but the samples our field expedition team (figure 23) collected from the three independent sources will help our gemologists characterize this deposit. Such systematic collection is necessary in order for labs to reliably explore the origin determination of spinel. GIA’s Bangkok laboratory is currently preparing an



Figure 23. The GIA field expedition team poses at Daw Nan Gyi Hill, in front of Pingu Thuang Mountain. From left to right: the author, Lou-Pierre Bryl, and Jordan, our friend and driver from Mogok. Photo by U Wanna, © GIA.

in-depth study of these incredible little gems for future publication.

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A LOOK INSIDE A REMARKABLY LARGE BEADED SOUTH SEA CULTURED PEARL

Laura M. Otter, Ursula Wehrmeister, Frieder Enzmann, Martin Wolf, and Dorrit E. Jacob

An exceptionally large, lustrous baroque-shaped South Sea cultured pearl from Indonesia was studied by high-resolution X-ray computed microtomography (X-ray μ -CT). The undrilled specimen measured 34.6 mm wide and 40.3 mm long. It was hollow and contained a loose bead. Analysis revealed a large internal cavity filled with liquid, gas, and organic material. The nacre thickness averaged 2.3 mm, and the bead measured 9.1 mm, both well within the typical ranges for South Sea cultured pearls. It is proposed that the cavity was originally occupied by spongy, water-bearing organic material, which inflated the pearl sac and provided a supporting surface for nacre deposition at a distance from the bead. After the nacre coating fully enclosed the organic material, gases were liberated and trapped inside the pearl.

South Sea cultured pearls, cultivated using the bivalve *Pinctada maxima*, have an average size of about 13 mm (Strack, 2006). The shells reach sizes above 30 cm, making them the largest known pearl mussel and enabling the production of the largest commercially traded cultured pearls, with diameters occasionally above 20 mm (Strack, 2006). Currently, the primary production areas include Indonesia, Fiji, Tahiti, the Philippines, Myanmar, and the western and northern coasts of Australia. Relatively high tolerance to environmental influences (Strack, 2006) and the size of the pearls produced make this mollusk one of the most interesting species for culturing.

The cultured pearl's colors correspond to the color of the donor bivalve's lip (Elen, 2001; Strack, 2006), which is the epithelial tissue at the nacreous margin on the inner part of the shell. The overtone colors

typically range from pink and green to blue (Gervis et al., 1992; Elen, 2001). It is common practice to reuse the cultured pearl sac several times, with successively larger cultured pearls formed. In addition, large nonbead-cultured pearls, as well as South Sea keshi pearls, occur either by chance or through cultivation (Hänni, 2006, 2007). Irregularly shaped baroque specimens are sometimes hollow or contain a loose bead. Yet they rarely reach the size of the exceptional cultured pearl described here.

X-ray computed microtomography (X-ray μ -CT) is a nondestructive method and thus ideally suited for the study of valuable pearls. Sample preparation is minimal (Wehrmeister et al., 2008; Karampelas et al., 2010), and analyses are carried out at ambient pressures. Methods requiring vacuum could cause severe damage to hollow pearls (Sturman, 2009). High-resolution digital X-ray images produced by X-ray μ -CT can be used to differentiate between aragonite and vaterite, the latter of which is responsible for the lack of luster in freshwater pearls (Wehrmeister et al., 2007, 2008). Lastly, Krzemnicki et al. (2010) showed that μ -CT radiographs are more effective than traditional radiographic images in resolving internal features of natural and cultured pearls.

MATERIALS AND METHODS

Our specimen was an undrilled, silver-colored baroque cultured pearl, with a pink to blue overtone, (figure 1) cultivated in *Pinctada maxima*. It was made available for analysis by the owner. The lustrous 34.6 × 40.3 mm specimen was cultured on the Indonesian island of Lombok (figure 2), which hosts a number of pearl farms in well-protected bays that provide excellent pearling conditions for *Pinctada maxima* (Zwaan and Zwaan, 1997).

Computed X-ray microtomography was carried out using a Procon X-Ray CT-Alpha commercial instrument at the Institute for Geosciences, Johannes Gutenberg University. The device and methods were largely identical to those used by Karampelas et al. (2010), though optimized using an accelerating volt-

See end of article for About the Authors and Acknowledgments.

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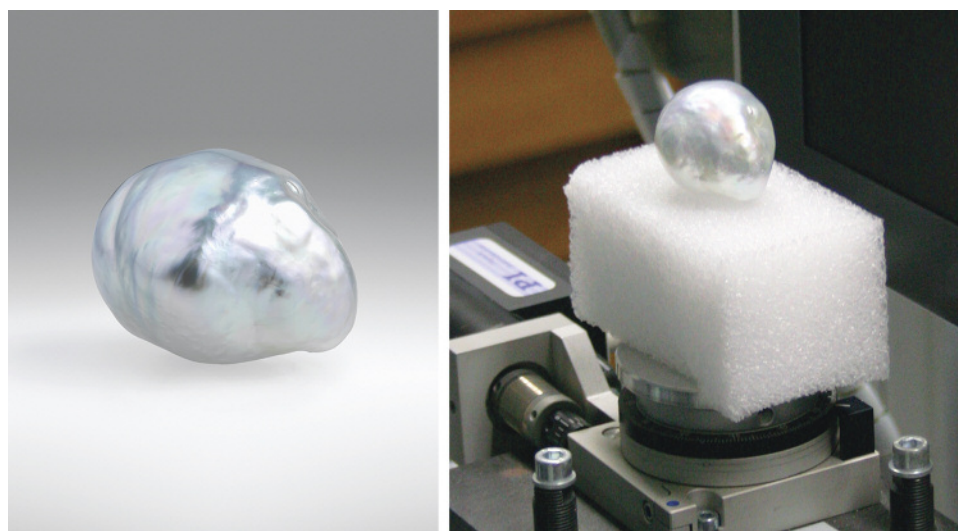


Figure 1. The cultured pearl specimen is shown before analysis (left) and mounted and ready for X-ray μ -CT analysis (right). Photos courtesy of Gellner GmbH & Co. (left) and M. Förster (right).

age of 100 kV and a target current of 120 μ A. The beam was pre-filtered by a 1.0 mm thick aluminum foil. The sample was mounted on a rotation stage at a distance of 250 mm from the X-ray tube for optimal magnification and resolution. We recorded 800 projections over 360°, with an average of 10 images per projection and an acquisition time of 1.5 seconds per image. This resulted in a dataset with 22.4 μ m per voxel (volume pixel) spatial resolution. Data processing was carried out with Octopus 8.5 commercial software and Avizo Fire 7.0 3D analyzing software.

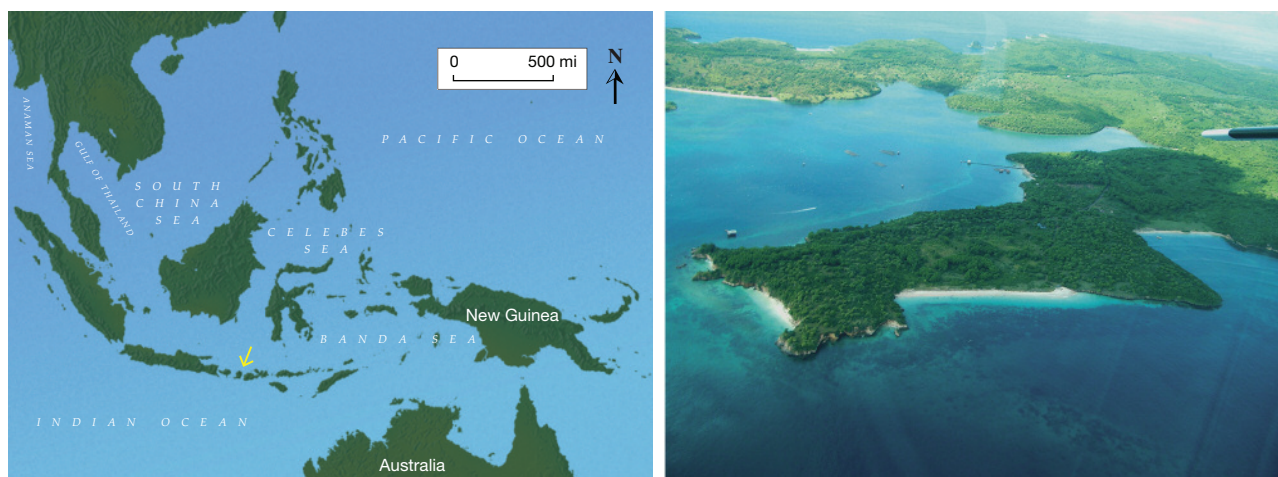
RESULTS

Figure 3A shows a large cavity that occupies most of the specimen's interior. The bead is 9.08 ± 0.02 mm in diameter and loose (i.e., not in direct contact with the underlying nacre). Based on 18 measurements,

the nacre thickness varies between 0.9 and 3.3 mm, with an average thickness of 2.3 ± 0.7 mm. Along much of the interior, narrow layers of nacre protrude inward into the large cavity (figure 3A, yellow arrow). Two irregular nacre regions were observed protruding outward; one has a very thin nacre coating of 0.9 mm. The thicker one is shown in figure 3A, and indicated with a white arrow.

Apart from the nacre and bead, which have high X-ray densities and appear light gray in figures 3A and 3B, several different phases with distinct X-ray densities could be distinguished by their grayscale values within the cavity. Phase 1, with the lowest X-ray density (dark gray or black appearance), was situated in the uppermost part of the cultured pearl. This phase was separated from phase 2 by a meniscus in the lower portion. Phase 3 was spread out across

Figure 2. The map of Indonesia on the left indicates the island of Lombok (yellow arrow), where the pearl was cultured. The aerial photo on the right shows Lombok's small bays, which are used for pearling.



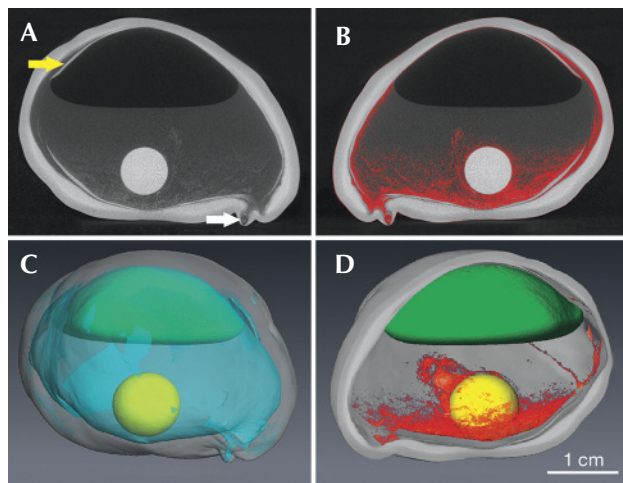


Figure 3. A: In this X-ray section, nacre and bead appear light to medium gray due to their higher X-ray densities. A thin layer of nacre is marked by a yellow arrow, while the white arrow points to a cone-shaped region of very thin nacre. B: Gas phase 1, with very low X-ray density (almost black), is in the upper part of the cavity, above the denser liquid phase 2. Phase 3 is in red at the bottom of the cavity. Note the meniscus between phases 1 and 2. C: The outer nacre (gray), gas (green), liquid (blue), and bead (yellow) are seen. D: The bead (yellow), phase 1 (green), and phase 3 (red) are shown. Liquid phase 2 is rendered transparent for better visibility of the organic phase. The blue spot in the nacre layer in the upper right of phase 3 is an artifact of the method.

the lower part and the sides of the cavity (red in figure 3B), providing a base and partial cover for the bead. Judging from its grayscale similarities to the ambient air around the specimen, phase 1 is interpreted to be a gas phase. Phase 2, on the other hand, showed a meniscus toward phase 1, which is typical for a liquid-gas interface. The noise produced from shaking the pearl confirmed that this phase was a liquid. Phase 3 had grayscale values between that of phase 2 (liquid) and the nacre. It had a spongy appearance (red in figure 3B) and extended in finger-like shapes above and partially along the bead. This phase likely represented organic material. No inorganic phase was observed in this area. In total, phase 2 (liquid), with a volume of approximately 6 mL (table 1), was the most abundant phase after the nacre, while phase 1 (gas) occupied approximately half the space of the liquid phase. Phase 3 (organic) was the least voluminous phase.

With the current state of analytical instruments, no further nondestructive methods could be employed to identify the content of this sample. One destructive option would be to release the liquid and

gaseous contents for analysis by drilling (with gas chromatography, for instance). This would risk severely damaging the sample, however.

DISCUSSION

This specimen was far above average size, as most Australian and Indonesian baroque cultured pearls range from 12.5 to 13.0 mm (Strack, 2006). Only a small percentage of baroque-shaped South Sea cultured pearls are known to have reached 40 mm in size (Strack, 2006), but none have matched the total volume of the example studied here. The specimen's average nacre thickness of 2.3 mm fell within the average South Sea range of approximately 0.5–4.0 mm (Strack, 2006). This indicates nacre growth rates

In Brief

- X-ray μ -CT of a 34.6 \times 40.3 mm South Sea cultured pearl showed a loose bead in a large cavity filled with gas, fluid, and organic material.
- The exceptional size of the specimen results from growth in a strongly inflated pearl sac.
- Inflation in the pearl sac was most likely caused by inflammation or contamination of the first layer of organic material during the pearl's growth.

comparable to those of other South Sea cultured pearls and shows that the specimen's large size was not caused by abnormally fast growth. The bead also compared favorably with the range of bead sizes commonly used for the first grafting of *Pinctada maxima* (Strack, 2006). Therefore, the characteristic differences between this specimen and other baroque cultured pearls were its unusually large size and the exceptional volume of its cavity. Table 1 shows that the cavity measured 9.65 cm³, comprising slightly over half of the total volume.

Templates for Nacre Deposition. A beaded pearl is grown by inserting a bead into the mussel tissue or gonad, along with a tissue graft that has the potential to secrete nacre. These tissue cells subsequently multiply into a pearl sac that eventually encloses the bead and generates a sheltered compartment for the creation of the pearl (Akamatsu et al., 2001; Landmann et al., 2001). In most cases, a cultured pearl's shape and size depend heavily on the shape and size of its bead. From our observations and from those of others, nacre coating of the bead usually starts with a thin layer of

organic material deposited on the bead, followed by regular nacre secretion until the pearl is harvested (Casseiro, 1993; Jacob et al., 2008). Round shapes are obtained when the bead, the organic layer, and the nacre are in contact with each other, providing a more stable surface (a so-called template) for the regular deposition of nacre layers. In cases where the bead is removed—upon rejection by the bivalve, for instance—the pearl sac collapses and flat pearls are formed. This specimen showed the opposite effect from a very rare instance of an inflated pearl sac; in this case, an exceptionally large cultured pearl was formed without bead removal when the pearl sac inflated.

The pearl contained a loose bead, much smaller than the pearl itself, and thus the nacre coating could not have been formed in contact with the bead. Similarly hollow pearls filled with liquid and smaller organics are known, occurring both naturally and from culturing (Sturman, 2009). The latter sometimes display loose beads as well.

Although a solid surface is generally required for nacre deposition, nonbead-cultured pearls demonstrate that the surface does not have to be rigid. The center of a nonbead-cultured pearl typically contains an organic “core,” which can be used to distinguish them from natural pearls (Hänni, 2006; Karampelas, 2010). This organic core represents a striking analogy to the first layer of organic material deposited on the bead in beaded cultured pearls. We propose that this organic material was not an accidental inclusion in addition to the bead; rather, it represented the organic template. It is regularly produced by the pearl sac at the start of nacre deposition in beaded pearls as well (Jacob et al., 2008), and we propose that this

organic material expanded and supported the formation of a pearl sac much larger than normal. This process may bear some similarities with a new development seen in cultured pearl production. Cartier and Krzemnicki (2013) describe the use of a newly developed organic nucleus that is highly absorbent. Initially compact, it grows into a large gelatinous nucleus after insertion into the gonad of the mussel. Since the tissue graft stays in contact with the swelling organic nucleus, this process results in an inflated pearl sac, eventually producing large baroque pearls (the first generation containing the gelatinous nucleus is not sold, according to the authors). A critical difference between this novel culturing method and the hypothesis proposed for our specimen is that we infer an expanded organic layer coating of the bead nucleus rather than an expanding nucleus.

Thus, we propose that the nacre in this exceptionally large cultured pearl was deposited on an organic template that forms regularly as the first product of nacre secretion. To support such a large pearl, the organic template must have originally occupied much of the space between the bead and the nacre, as seen in figure 3. This clearly represents a departure from normal conditions.

Figure 3A shows some layers of nacre flaking off toward the interior (see the yellow arrow). We believe it is an effect of nacre deposition on an unstable template provided by organic material with little support from the bead.

Hollow Pearls with Organic Fillings. Our evidence suggests that the pearl’s interior was filled with a spongy mixture of organic material (perhaps tissue) and water that provided physical support for the deposition of the nacre coating. This also indicates that the pearl sac did not fully enclose the bead, meaning it did not heal completely after surgery, providing an opening for water to enter. Net-like remnants of the organic phase could still be seen enclosing the bead (figure 3D). It is likely that some of this material was introduced upon grafting and due to proliferation following a bacterial infection or other accidental inclusions or contamination of tissue material.

In due course, the organic material within the nacreous coating decayed, liberating foul-smelling gases that collected at the top of the pearl (figure 3C). Indeed, “organic odors” have been detected upon drilling or otherwise breaking open hollow pearls (Sturman, 2009).

The pearl had a small area where the nacre coating was only 0.9 mm thick (figure 3). This area probably represents a perforation in the nacre coat, which could

TABLE 1. Relative abundances of the different phases of the cultured pearl specimen.^a

	Volume (cm ³)	Vol. %
Nacre	7.72	44
Phase 1 (gas)	3.40	19
Phase 2 (liquid)	6.06	34
Phase 3 (organics)	0.19	1
Total cavity (1+2+3)	9.65	54
Bead	0.39	2
Total pearl	17.76	100

^aVolumes assigned to specific X-ray grayscale of the various parts of the specimen were calculated by software. As the cultured pearl contains multiple dimples, the volume was found to be less than that of an ideal ellipsoid.

have allowed the liquids and gases to penetrate or leak from the pearl. The average growth rate for nacre in South Sea pearls is approximately 1 mm per year (Strack, 2006). Assuming normal growth rates for this very thin area, the perforation must have remained open throughout most of the growth period of this remarkable specimen.

CONCLUSION

Nondestructive analysis of this exceptional cultured pearl by X-ray μ -CT revealed a multi-phase cavity filled with liquid, gas, and organic material. The cavity measured approximately four times larger than the bead in diameter, which raises the question of

how the nacre coating was physically supported during pearl growth. The model presented here argues that the organic material played an important role. We submit that pathological proliferation of tissue material after grafting, possibly due to a bacterial infection, inflated the pearl sac while the enclosed spongy organic material acted as a template providing support for pearl growth. Once enclosed in nacre, the organic material decayed, liberating gases that had collected inside the pearl.

The proposed model may well represent a viable process for the formation of hollow pearls. If bacterial infections are involved, such products represent true "survivors," underscoring the exceptional nature of this large South Sea cultured pearl.

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TAKE THE 2014 GEMS & GEMOLOGY CHALLENGE

The following 25 questions are from the Spring, Summer, Fall, and Winter 2013 issues of *GEMS & GEMOLOGY*. Refer to the articles in those issues to find the **single best answer** for each question.

Mark your choice on the response card provided in this issue or visit gia.edu/gems-gemology to take the Challenge online. Entries must be received no later than **Friday, August 1, 2014**. All entries will be acknowledged with an e-mail, so please remember to include your name and e-mail address (and write clearly).

Score 75% or better, and you will receive a certificate of completion (PDF file). Earn a perfect score, and your name also will be listed in the Fall 2014 issue of *GEMS & GEMOLOGY*.



- Moganite, a monoclinic silica phase, thrives in the presence of what two things?
 - Ferric iron and alkaline fluids
 - Acidic conditions and calcium-rich fluids
 - Titanium and ferrous iron
 - Organic substances and hydrogenic conditions
- Which UV-Vis-NIR bands, observed in SWCPs from allografted *P. margaritifera* and xenografted *P. maxima* host and *P. margaritifera* donor, were not observed in untreated allografted *P. maxima* SWCPs?
 - 405 and 495 nm
 - 405 and 700 nm
 - 495 and 700 nm
 - 330–460 and 700 nm
- If you bought “siclin” in a gem market in Luc Yen, what would you have?
 - Sapphire
 - Spinel
 - Chalcedony
 - Citrine
- Standard long-wave (LW) and short-wave (SW) ultraviolet lamps often _____.
 - are too expensive for the average jeweler
 - contain LED light sources
 - demonstrate no adverse effects with aging
 - produce extra emission peaks
- What is most likely true about the three sunstone mines in Oregon?
 - All are in Lake County.
 - The gems from each are found exclusively in basalt flows.
 - A single magma chamber may have produced all of their feldspar phenocrysts.
 - Most mining occurs in springtime.
- The auction of which diamond led to a larger global market for fancy-color diamonds?
 - Hancock Red
 - Sun Drop
 - Vivid Pink
 - Wittelsbach Blue
- Which characteristic may be indicative of coated jadeite?
 - Scratches on the surface.
 - Presence of a 437 nm absorption band.
 - A slightly sticky feel.
 - A deep green uniform color.
- During the 17th century, which stone was believed to turn hot in the presence of poisons?
 - Toadstone
 - Ruby
 - Carnelian
 - Garnet
- Protecting elephants from extinction requires the ability to differentiate between modern and fossil ivories. Which of the following is NOT true?
 - Fossil ivory is less compact than modern ivory.
 - Trace elemental analysis of strontium and barium will not allow for a separation.
 - The Schreger angles of modern and fossil ivories are clearly distinguishable.
 - Collagen is present in modern

- ivory but absent from fossil ivory.
10. Why are natural diamonds rare?
 - A. Very little of the mantle qualifies as being within the field of diamond stability.
 - B. The extraordinary temperature and pressure conditions needed for diamond formation are rare on Earth.
 - C. Earth's geologic activity has been too limited to create many diamonds.
 - D. There is not much carbon in the mantle of the earth.
 11. What is responsible for the layered distribution of color within the digits of some opal?
 - A. Chemical impurities
 - B. Gravity
 - C. Polygonization
 - D. Dehydration
 12. Which factor enhances the apparent brightness of a faceted gem?
 - A. Strong contrast
 - B. Maximized observer reflection
 - C. Diffused lighting
 - D. Increased color saturation
 13. The most valuable diamonds for research purposes are _____.
 - A. colorless and flawless diamonds
 - B. fancy-color diamonds
 - C. those that are clearly more than 2.7 billion years old
 - D. those with visible inclusions
 14. Which diamond color center is most often observed among colorless diamonds?
 - A. N-V
 - B. H3
 - C. N3
 - D. H4
 15. A mere ____ of all diamonds mined annually meet fancy-color grade requirements.
 - A. 0.002%
 - B. 0.001%
 - C. 0.0001%
 - D. 0.0002%
 16. What are "virtual" facets?
 - A. Dark facets caused by overhead light obstruction from the observer's head.
 - B. Additional facets observed beyond the actual number of cut facets.
 - C. Facets cut at angles that maximize light return.
 - D. Tiny facets that look fuzzy.
 17. What is the most common cause of red phosphorescence in diamond?
 - A. Nitrogen
 - B. Boron
 - C. Hydrogen
 - D. Nickel
 18. Sunstone, the state gemstone of Oregon, can be challenging to cut, as _____.
 - A. achieving an adequate polish is difficult
 - B. they tend to be fractured, limiting the ability to orient around the interior colors
 - C. rough over 2 ct in size is hard to obtain
 - D. stones with adequate body-color are extremely rare
 19. Moonstones reportedly from Donghai County in Jiangsu province exhibited strong blue adularescence. Examination by China's National Gold & Diamond Testing Center determined that the stones were subjected to which type of treatment?
 - A. Irradiation
 - B. Diffusion
 - C. Oiling
 - D. Impregnation
 20. Many gem materials are found in marble in the Luc Yen mining district of Vietnam. Which is NOT found in marble in this area?
 - A. Pargasite
 - B. Ruby
 - C. Spinel
 - D. Tourmaline
 21. An imitation spinel found in the Cheapside Hoard was actually _____.
 - A. foil-backed glass
 - B. colored glass
 - C. quench-crackled and dyed quartz
 - D. flame-fusion spinel
 22. Which of the following statements is true about saltwater cultured pearls (SWCPs)?
 - A. Most commercial SWCPs are cultivated through xenotransplantation.
 - B. The saibo is responsible for SWCP coloration, but not nacre thickness.
 - C. Generally, spectroscopy can be used to identify the donor mollusk species.
 - D. The saibo and bead are implanted separately into the host mollusk.
 23. The inclusions in sapphire from Baw Mar are _____.
 - A. mainly rutile
 - B. numerous and found in almost all samples
 - C. very similar to those found in Mogok sapphire
 - D. generally fissures that may contain epigenetic materials
 24. Red to brownish red inclusions in surface-reaching fractures of sapphire may indicate _____.
 - A. flux growth
 - B. diffusion
 - C. bleaching
 - D. heating
 25. The relatively low specific gravity observed in some nephrite jade samples from Val Malenco can be attributed to _____.
 - A. excess galena
 - B. lower concentrations of iron and chromium
 - C. higher amounts of calcite
 - D. a lack of molybdenite



Editors

Thomas M. Moses | Shane F. McClure

**UV-Reactive OPAL**

A pair of milky white polished opals, weighing 2.66 and 2.48 ct, were recently examined at the Carlsbad laboratory (figure 1). Spot RI readings of 1.44 and 1.43, respectively, were consistent with opal. The stones were placed under long-wave ultraviolet light (LWUV) as part of the routine testing.

Upon removal from the UV light source, it was apparent that the opals' color had changed to a bright orangy red. Further gemological testing confirmed that the specimens had been impregnated with an unknown photochromic substance that changed color when exposed to UV light. The color change (figure 2) occurred after approximately one minute of exposure. The orangy red color faded completely about five minutes after removal from the UV source. Furthermore, when the specimens were placed near a window, sunlight provided enough UV radiation to fully induce the orangy red color. This reversible and repeatable effect, known as tenebrescence, is occasionally seen in natural materials, most notably hackmanite. Exposure to the light of an incandescent bulb faded the color faster, which is another property of tenebrescence. Exposure



Figure 1. Note the milky white color of these two polished opals before exposure to long-wave ultraviolet light.

to short-wave UV did not produce any visible effect on the color.

The fact that hydrophane opal allows foreign substances to be introduced has already been established (N. Renfro and S. McClure, "Dyed purple hydrophane opal," Winter 2011 *G&G*, pp. 260–270). This was in

Figure 2. The same two opals are shown after exposure to long-wave UV.



the context of dyeing with a substance that altered the appearance of the bodycolor, but did not change color in the presence of UV light. Impregnating opal with a UV-reactive chemical to make the opal appear to be tenebrescent has not been previously documented. Whether the substance used to impregnate the opals affected the original color or transparency is not known, nor is the stability of the treatment.

Troy Ardon

Assembled "PEARL" Filled with Wire

The excitement of being the first person to observe a pearl's interior is always foremost in one's mind when performing microradiography tests on a newly submitted specimen. Baroque pearls in particular have a higher probability of revealing something unusual (see Fall 2013 Lab Notes, pp. 172–173), since they often contain internal voids that are ideal for filling if exposed by damage or excessive drilling.

A light yellow and cream baroque pearl (figure 3), weighing 10.97 ct and measuring 12.74 × 11.60 × 11.14 mm, was recently submitted with seven others to the Bangkok laboratory for a GIA Quality Assurance Report, which provides rapid identification for sorting goods. Prior to microradiography, the pearl immediately appeared suspect because it was circled by an eye-visible band that indicated some "work" had likely been carried

Editors' note: All items were written by staff members of GIA laboratories.

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Figure 3. In this 10.97 ct baroque pearl, a suspect ring circling the surface is clearly visible.

out. This was confirmed by examination with a loupe and microscope, which revealed a lustrous, transparent bonding agent. Small black impurities of an unknown nature were present in the bonding agent (figure 4). The type of work performed on the pearl was instantly confirmed by microradiography (figure 5). Looking at the microradiograph, it was obvious that two coiled wire fillings had been placed in the void between two hollow pearl pieces.

This is not the first time that metal wire has been encountered in pearls (see K. Scarratt, "Notes from the Laboratory," *Journal of Gemmol-*

ogy, Vol. 20, 1986, p. 95), but it appears to be the first time two different hollowed halves have been assembled with a piece of wire in each. While there is little doubt that this specimen was fabricated to increase its weight and create a "single" pearl, the alterations were so severe that they removed critical internal structure, making the components difficult to identify. The two specimens may have been natural pearls with internal voids, bead-cultured pearls with voids around the bead (as is common), non-bead cultured pearls, or any combination of these. We therefore concluded that the "pearl" should be described as "undetermined" but filled.

Nanthaporn Somsa-ard and
Areeya Manustrong

CVD SYNTHETIC DIAMOND with Unusual DiamondView Image

Over the last several years, CVD-grown synthetic diamonds have evolved rapidly in overall quality, including size and clarity. GIA's laboratory frequently documents new, sometimes subtle developments in this material.

Recently a 0.32 ct, G-color CVD synthetic (figure 6) was submitted to the Carlsbad laboratory. DiamondView imaging (figure 7) showed a few interesting characteristics. Most of the sample displayed a deep blue fluorescence, a feature typically derived from the N3 optical center and often

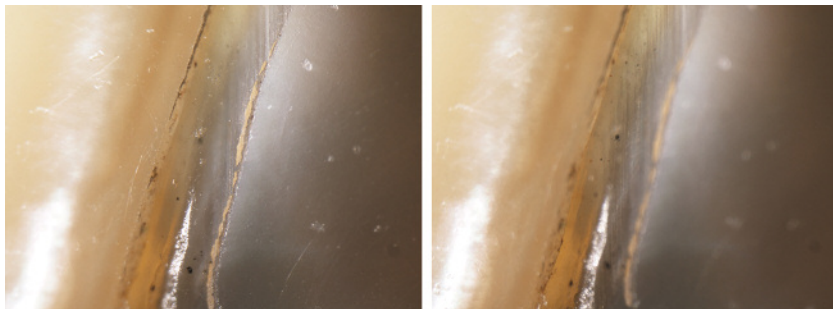


Figure 4. The area between the two parts assembled to form the "pearl" revealed creamy areas of deterioration where the bonding agent met the pearl components (left) and very small black impurities of an unknown nature trapped within the agent (left and right). Magnified 70x.

observed in natural diamonds. CVD-grown synthetic diamonds usually have either a greenish blue or an orange to red fluorescence, depending on whether they have been treated to generate high concentrations of NV centers. The deep blue, N3-related fluorescence is so prevalent among mined diamonds that the color itself can often verify that a diamond is not synthetic. In addition to the deep blue color of the fluorescence, its visual pattern closely resembled the dislocation networks commonly seen in natural-origin type IIa diamonds rather than the striations caused by stepwise growth in CVD synthetics (P.M. Martineau et al., "Identification of synthetic diamond grown using chemical vapor deposition [CVD]," *Spring 2004 GeJG*, pp. 2–25).

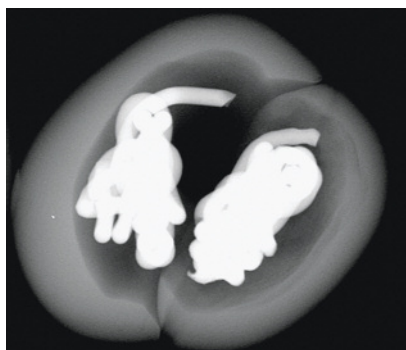


Figure 5. The internal structure revealed two very distinct pieces of coiled wire (metal is radio-opaque) within voids whose outlines did not match. The mismatched outlines helped prove that two separate specimens were combined to form the new "pearl."

Figure 6. This G-color, 0.32 ct CVD-grown synthetic showed DiamondView features typically associated with a natural origin.



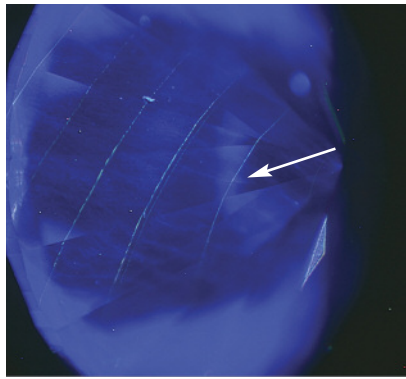


Figure 7. In addition to blue fluorescence, the CVD synthetic's DiamondView image displayed yellow-green fluorescence lines indicating the stop/start cycling that occurred during the growth process.

Taken together, the blue fluorescence and apparently random patterning closely resemble DiamondView images of natural-origin type IIa diamonds. This indicates that CVD manufacturers are becoming quite adept at mimicking natural growth. It is unclear whether this resemblance was a deliberate goal or a by-product of advances in CVD growth; regardless, the blue fluorescence for this CVD synthetic diamond does not appear to derive from the N3 center. Photoluminescence (PL) spectroscopy, collected with 325 nm excitation, showed only a very weak peak at 415.2 nm.

Yet this stone also contained two features that clearly indicated its synthetic origin: a large concentration of the Si-V center at 737 nm, revealed by PL spectroscopy, and the pronounced yellow-green parallel lines in the DiamondView image.

These parallel lines, with a nearly uniform spacing of approximately 0.8 mm in this sample, are created when the CVD reactor undergoes stop and start cycles during growth. These cycles create a temporary change in chemical composition, especially at the growth interface. Willems et al. ("Exploring the origin and nature of luminescent regions in CVD synthetic diamond," Fall 2011 *G&G*, pp. 202–207) proposed that a change in surface roughness promotes the in-

corporation of impurities, which alters the fluorescence and creates new dislocations.

Four PL spectra were collected from these yellow-green lines and from the blue-fluorescing regions, using 488 nm laser excitation and normalized to the Raman peaks. The relative intensities of the peak areas from both regions were averaged to compare the optical defects that altered the fluorescence. The H3 center at 503.2 nm, the NV centers at 575 and 637 nm, and the Si-V center at 737 nm all showed higher concentrations along the yellow-green lines. These vacancy-related defects increased by a factor of approximately 1.5 for NV⁰ and Si-V, 3 for NV⁻, and 5 for H3, indicating a higher presence of vacancies at the growth interface. Several sequential growth runs were likely necessary to achieve high CVD quality, leaving behind these fluorescence lines as evidence of synthetic origin.

Sally Eaton-Magaña

Round CVD SYNTHETIC DIAMOND Over 1 Ct Identified in Hong Kong Lab

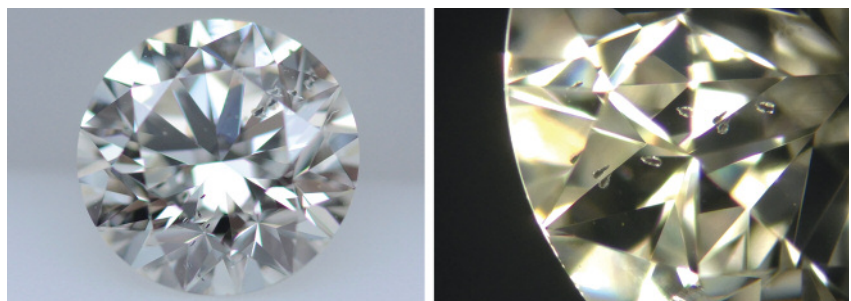
In the past ten years, CVD synthetic diamonds have showed significant improvements in quality and size (Martineau et al., Spring 2004 *G&G*, pp. 2–25; Wang et al., Winter 2003 *G&G*, pp. 268–283; Wang et al., Summer 2012 *G&G*, pp. 80–97). Their color and clarity can be comparable with top natural counterparts, but for the most

part they are still small. CVD gem-quality synthetic diamonds over 1 ct are occasionally reported in the trade, usually in fancy shapes with limited depth.

Recently, a round-brilliant specimen, identified as a CVD synthetic diamond, was submitted to the Hong Kong laboratory for grading service. It weighed 1.20 ct (6.70 × 6.72 × 4.30 mm), with a color grade of L, a clarity grade of SI₂, and a cut grade of Very Good. This specimen resembled well-cut natural round diamonds (figure 8, left), with a few black inclusions of irregular shape clearly observable under the microscope (figure 8, right).

Infrared absorption spectroscopy identified it as type IIa. A very weak absorption at 1344 cm⁻¹ was attributed to isolated nitrogen in the diamond lattice (figure 9). Based on the absorption intensity (0.014 cm⁻¹) of this peak, the total concentration of isolated nitrogen was well below 1 ppm. Occurrence of trace isolated nitrogen was the major optical center responsible for the L color observed. No hydrogen-related absorption was observed at either 3107 or 3123 cm⁻¹ using infrared absorption spectroscopy. Photoluminescence (PL) spectra at liquid nitrogen temperature with 532 nm laser excitation showed the [Si-V] doublet emissions at 736.6 and 736.9 nm (figure 10), a characteristic feature of CVD synthetic diamond. Weak emissions from N-V centers at 575.0 nm and 637.0 nm were also recorded. Fluorescence images collected using the Diamond-

Figure 8. Left: This 1.20 ct CVD synthetic round brilliant had a color grade of L, a clarity grade of SI₂, and a cut grade of Very Good. Right: The 6.7 mm specimen contained a few black inclusions with irregular shapes.



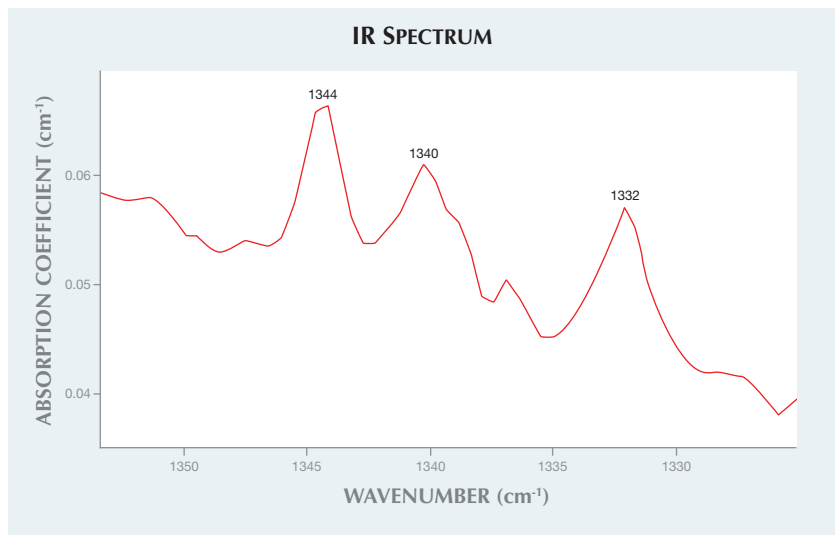


Figure 9. The CVD synthetic diamond's infrared absorption spectrum showed a weak peak at 1344 cm^{-1} . This feature, attributed to the isolated nitrogen impurity, was responsible for the L color grade.

View showed green fluorescence with characteristic CVD growth striations (figure 11). All these gemological and spectroscopic observations, very similar to those of Gemesis specimens (Wang et al., 2012), confirmed this was a CVD synthetic diamond. It was annealed at high pressure and high temperature (HPHT) to improve its color appearance.

As this sample shows, CVD technology has reached a new milestone, with the growth of crystals thick enough to consistently cut well-proportioned round brilliants. It is highly likely that we will see more gem-quality CVD synthetic diamonds over 1 ct in the trade.

Carmen "Wai Kar" Lo, Ping Yu Poon, and Shun Yan Wong

Figure 10. A photoluminescence spectrum collected at liquid nitrogen temperature using 532 nm laser excitation revealed a strong emission doublet at 735.6 and 735.9 nm, indicating a [Si-V] optical center.

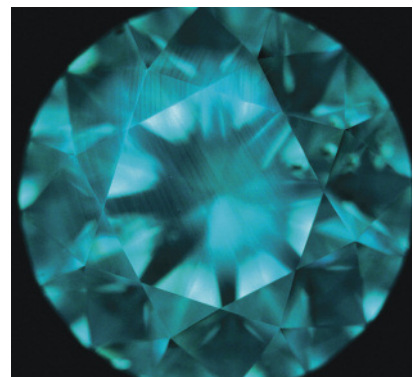
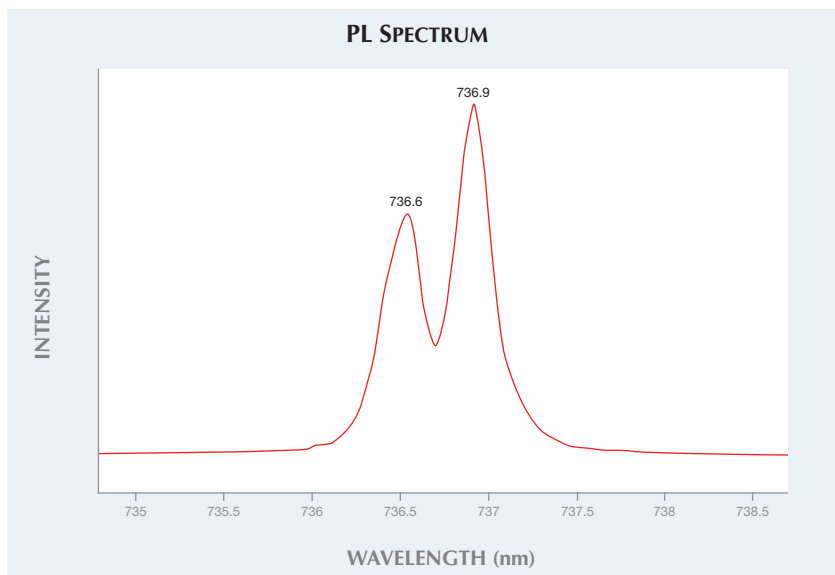


Figure 11. Observed in the DiamondView, the 6.7 mm synthetic diamond showed typical striations indicative of CVD growth.

Fancy Black NPD SYNTHETIC DIAMOND

As reported previously in *Gems & Gemology*, nano-polycrystalline diamond (NPD) growth technology is one of the most significant new developments in diamond synthesis (see E.A. Skalwold, "Nano-polycrystalline diamond sphere: A gemologist's perspective," Summer 2012 *G&G*, pp. 128–131). The material is completely transparent and comparable to natural diamond, while tougher than natural diamond or previous synthetic diamonds. NPD could pose a challenge to the natural diamond industry once these goods, particularly higher-quality transparent samples, enter the consumer market.

Recently, the New York laboratory tested a small, black marquise-cut stone for identification and color origin. At first glance, the 0.9 ct translucent specimen (figure 12) resembled a typical black diamond submitted to the lab for identification and color origin. One must be careful to separate such stones from synthetic moissanite. This marquise, however, revealed unusual properties strikingly similar to those of the NPD synthetic diamonds reported on by Skalwold, as well as other previously tested samples. These previously studied specimens were transparent with a yellow to brown range of color.

Unlike natural diamond, the stone in question was heavily included with graphite crystals. The



Figure 12. This 0.9 ct marquise proved to be a synthetic nanopolycrystalline diamond (NPD), the first one detected by a gemological laboratory.

matrix hosting the inclusions had a murky yellowish color (figure 13). Using diffuse reflectance, we obtained a mid-infrared absorbance spectrum strikingly similar to that of the NPD synthetic diamonds reported in the aforementioned article. We observed the diagnostic diamond absorption peaks at approximately

Figure 13. Photomicrograph images of the heavily included synthetic diamond showed an abundance of graphite inclusions and a murky yellowish matrix. Fields of view (clockwise from top left): 1.5, 3.1, 1.5, and 4.1 mm.

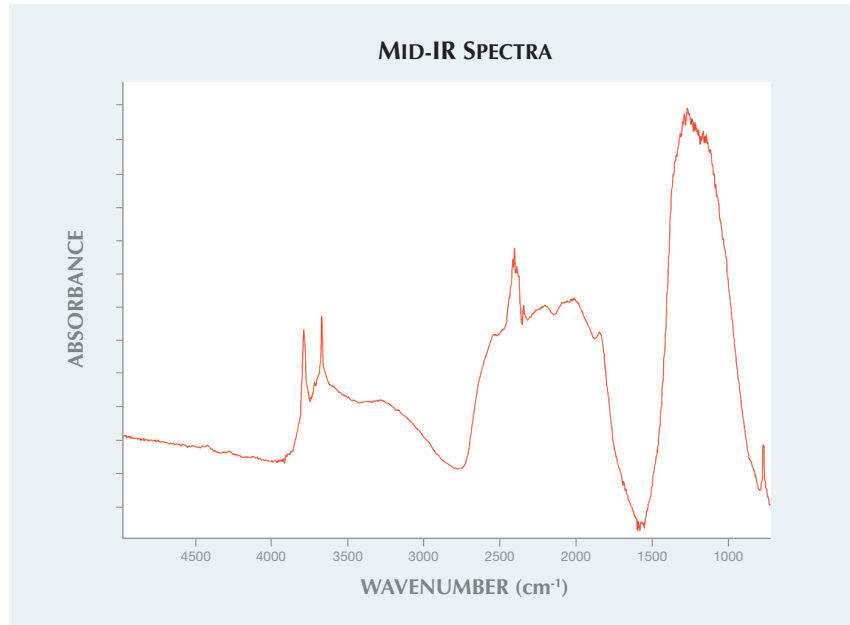
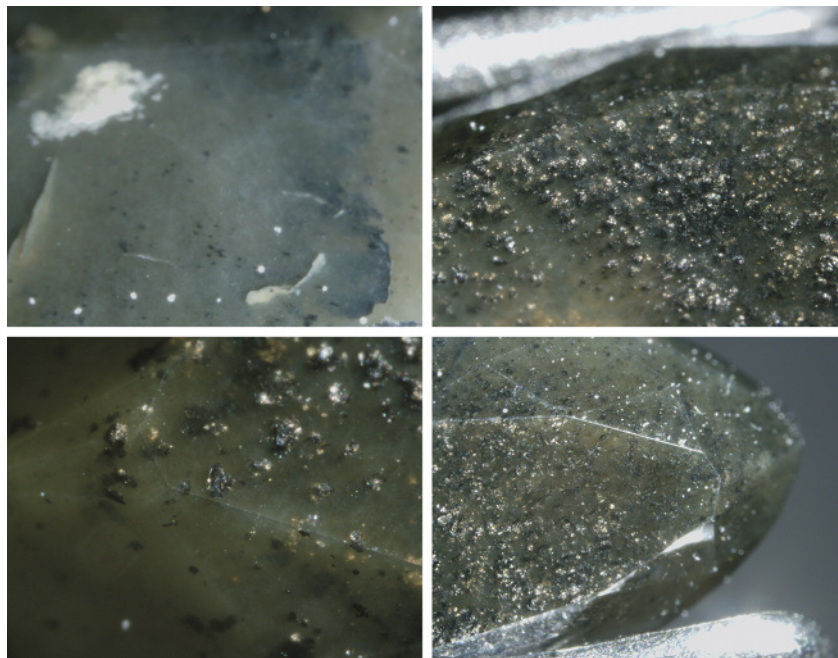


Figure 14. The mid-infrared spectrum of the synthetic NPD displayed peaks at approximately 3727 and 3611 cm^{-1} .

2000 cm^{-1} and absorption in the one-phonon region, possibly due to nitrogen impurity. Peaks at approximately 3727 and 3611 cm^{-1} were also observed, as in the previously tested

NPD samples (figure 14). Raman spectroscopy is a common and useful technique in identifying a gem diamond. Due to the nano-sizes of the crystals that compose the aggregated sample, a Raman shift is usually not detectable in NPD using visible-light laser excitations. The same feature was observed in this specimen.

Further analysis using the DiamondView instrument revealed a fluorescence pattern and structure that was, again, very similar to earlier NPD samples (figure 15). Raman analysis showed a broad band at approximately 1350 cm^{-1} and a weak band at about 1580 cm^{-1} ; these are assigned as D- and G-bands, respectively (S. Odake et al., "Pulsed laser processing of nano-polycrystalline diamond: A comparative study with single crystal diamond," *Diamond and Related Materials*, 2009, Vol. 18, pp. 877–880). Odake reported the two bands in NPD samples grown from high-purity graphite at a temperature of 2600K and a pressure of 15 GPa; both are caused by nanocrystalline graphite or amorphous carbon. Unlike Odake's samples, which showed G- and D-bands of equal intensity, ours showed a strong D-band with a weak G-band. We measured Raman spectra at many different locations but

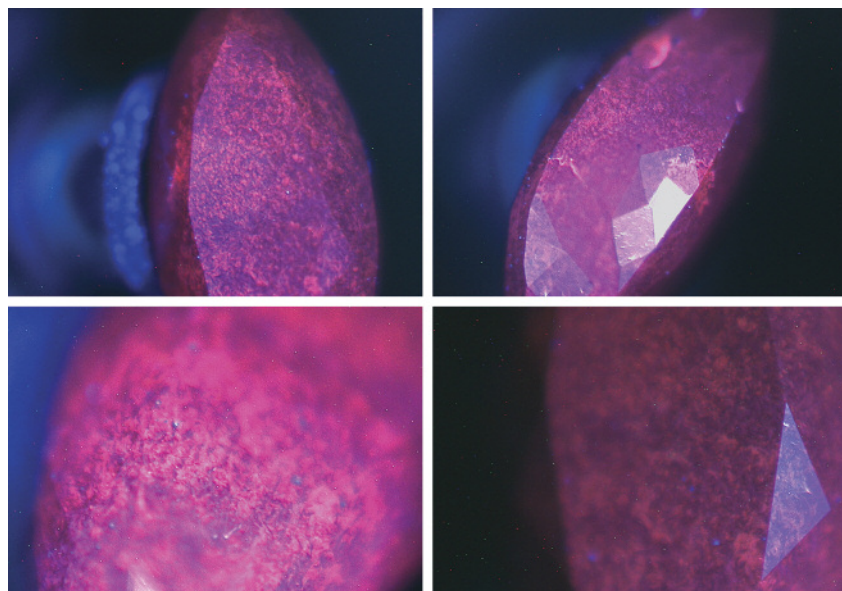


Figure 15. DiamondView images of the synthetic NPD exhibited a distinct fluorescence pattern.

did not observe the diamond Raman band at 1332 cm^{-1} , an absence Odake also reported.

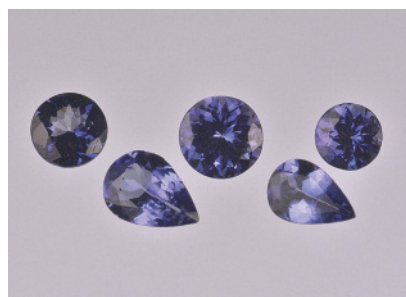
Testing and observations revealed the diamond to be an NPD synthetic diamond, the first detected by a gemological laboratory.

Paul Johnson and Kyaw Soe Moe

Titanium-Coated TANZANITE

Five faceted violetish blue stones, ranging from 0.39 to 0.82 ct (figure 16), were recently submitted to the Carlsbad laboratory for identification service. Standard gemological testing revealed a refractive index of 1.689–1.700 for all five samples. When observed using polarized light, each displayed a medium

Figure 16. These five tanzanite samples (0.39–0.82 ct) proved to be color-coated with titanium.



pleochroism. Specific gravity, measured using the hydrostatic method, was 3.37. These properties were consistent with tanzanite.

Microscopic examination showed that the material was relatively free of inclusions, but showed areas of abrasion along pavilion facet junctions. Observed using reflected light, the pavilion of each stone showed a significantly higher luster than the crown. Some individual facets even showed a variation in luster due to an unevenly distributed color coating (figure 17). When the samples were examined using diffuse transmitted light, the facet junctions and several

Figure 17. This upper portion of a pavilion facet, examined in reflected light, shows a much higher luster than the lower, uncoated portion. Field of view 1.22 mm.

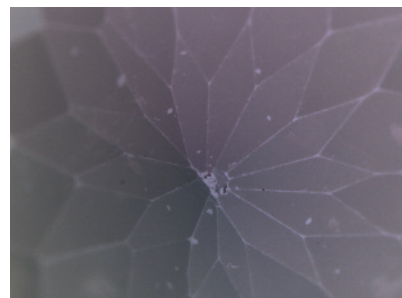
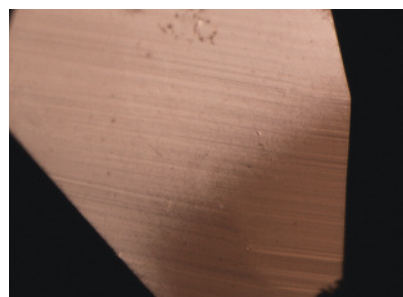


Figure 18. The coating on this tanzanite's pavilion has been worn away along the facet junctions and in some small chipped areas, revealing the less-saturated violet color of the tanzanite underneath. Field of view 2.90 mm.

chipped spots appeared much less saturated, which was also consistent with a color coating (figure 18).

Because tanzanite with a cobalt coating has previously been reported (S.F. McClure and A.H. Shen, "Coated tanzanite," Summer 2008 *G&G*, pp. 142–147), all tanzanites submitted to the lab are routinely checked by energy-dispersive X-ray fluorescence (EDXRF) and microscopic examination. These five stones were also checked by EDXRF, but no cobalt was detected; however, all five showed a significant signal for titanium on their pavilions. No titanium was detected on the crowns. LA-ICP-MS was also used to confirm that the coated area contained significant titanium.

While color-enhancing coatings on tanzanite are occasionally seen at GIA's laboratory, this is the first time we have examined tanzanite that has been color coated with titanium.

Amy Cooper and Nathan Renfro

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TUCSON 2014

Every February, exhibitors and buyers from all over the globe descend on Tucson, Arizona, for the annual gem and mineral shows that take place in conference spaces, tents, hotel rooms, and parking lots across the city (figure 1). This year a number of exhibitors noted the lack of Chinese buyers, who are now likely to make their purchases at the Hong Kong show for convenience. For many exhibitors, however, Tucson remains a very important venue in the year's trade show calendar.

For Alexander Wild (Wild & Petsch Lapidaries, Kirschweiler, Germany), the show was a place to write invoices and do "serious selling." While many clients were not shopping for any one particular gem, they were seeking out unique items: fine-quality gems as single pieces, matched pairs, sets, or suites. Exhibitors selling everything from cultured pearls to unheated tanzanite, Australian chrysoprase, and top-quality ruby, sapphire, and emerald echoed the same sentiment: fine goods were strong sellers.

Wild attributed the current shortage of gem rough to the global economic crisis that began in September 2008. The following years, he recalled, were "disastrous" for many in the colored gem trade, as their customers simply stopped buying. The resulting lack of liquidity cascaded down to active mining operations, especially in Africa and Brazil. Miners in those areas were left with no clients for their previously mined goods, and no income with which to purchase equipment or staples such as diesel fuel. Within a short time, Wild said, many operations were sad-

dled with debt and subsequently ceased operations. Mine workers returned to the agricultural sector, which began to rebound in 2009. By then, costs had become so prohibitive that many former operators could no longer afford to return to the mining industry.

One common refrain among exhibitors was the intense competition for scarce cutting rough, creating a dramatic price increase. Many mentioned stiff competition from Chinese buyers or their agents at the sources. Steve Ulatowski of New Era Gems (Grass Valley, California) told us the price of pink to red tourmaline rough has shot up due to Chinese demand. He cited Nigerian tourmaline rough that was priced at \$8,000 per kilogram several years ago; the current asking price for equivalent goods was \$200,000 per kilo, with sellers asking for cash on the table.

Many dealers also emphasized the importance of "re-circulated" gems or jewelry pieces, remarking on the high quality of pieces in the secondary market. These included fine sapphire, ruby, alexandrite, and cat's-eye chrysoberyl, gems that were otherwise unobtainable. All find a ready market in Asia.

Regardless of these powerful undercurrents, most of the exhibitors who spoke with us expressed satisfaction with their results from Tucson. Although traffic at some shows was down from previous years, exhibitors reported that buyers were serious and business was satisfyingly brisk.

All in all, the Tucson gem and mineral shows are a fascinating cross section of materials, sellers, and buyers that provides a unique window into a singular industry. We eagerly look forward to next year's shows.

G&G appreciates the assistance of the many friends who shared material and information with us this year, with special thanks to the American Gem Trade Association for providing photography studio space during the AGTA show. GIA's Eric Welch, Pedro Padua, Clara Zink, and Andy Lucas contributed to this report.

COLORED STONES AND ORGANIC MATERIALS

Cultured pearl market update. Fran Mastoloni (Mastoloni Pearls, New York City) updated us on the cultured pearl

Editors' note: Interested contributors should send information and illustrations to Justin Hunter at justin.hunter@gia.edu or GIA, The Robert Mouawad Campus, 5345 Armada Drive, Carlsbad, CA 92008.

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Figure 1. From the convention center to tented pavilions and hotels to parking lots, Tucson's many gem and mineral shows draw buyers of every stripe hungry for the earth's treasures. Photos by Eric Welch (top left), Stuart Overlin (bottom right), and Duncan Pay (top right and bottom left).

market during the AGTA show. He explained that for the past two years, the emphasis has been on long necklaces, double strands, and mixing different sizes, colors, and types of cultured pearls. These trends have reenergized the market, making pearls "fun to wear again." While weddings and graduations are still occasions for classic akoya-type necklaces and studs, there are now more opportunities to sell innovative blends of color and shape. Typical of this approach is the striking necklace with 15–17 mm Tahitian baroque cultured pearls shown in figure 2 (left). Such a piece might take three years to make and could retail for tens of thousands of dollars.

With production of Tahitian cultured pearls down, Mastoloni has been using smaller off-round, pastel-colored pearls to create distinctive, competitively priced necklaces.

These styles offer a "big" look for a relatively low price. The colors, including a subtle silvery gray, are all natural. Mastoloni stressed the importance of luster as a selling point.

South Sea cultured pearl production has been reliable and consistent in quality, but prices have fluctuated. While lower-quality specimens are inexpensive and readily available, high-quality pearls are expensive and difficult to obtain. Due to improvements in culturing processes—including the X-ray inspection of mollusks—baroque-shaped cultured pearls have become increasingly rare. When X-ray operators detect a non-round pearl, Mastoloni noted, they will restart the culturing process. As a result, fewer non-round shapes are available for baroque necklaces (figure 2, center).

Demand for fine cultured pearls from China has outstripped supply, with fine examples of all pearl types show-

Figure 2. Left: This strand of baroque cultured pearls from Tahiti is indicative of current jewelry trends. Center: Due to improved culturing techniques, baroque South Sea cultured pearl necklaces will become increasingly expensive and difficult to find. Right: These naturally golden cultured pearls from the Philippines range from 14 to 17 mm. China's increasing demand for them has pushed up prices and reduced availability elsewhere. Photos by Eric Welch; courtesy of Mastoloni Pearls.





Figure 3. This very fine 12–14 mm multicolor necklace was assembled piece by piece using Australian, Philippine, and Tahitian cultured pearls. Each cultured pearl is matched for size and shape, and all have exceptional luster. Photo by Robert Weldon.

ing surges in price. Golden cultured pearls from the Philippines (figure 2, right) have become increasingly costly and difficult to obtain, Mastoloni noted.

This scarcity of cultured pearls made the necklaces exhibited by Mastoloni all the more remarkable. They included an exceptional strand of multicolor specimens from Australia, the Philippines, and Tahiti (figure 3), as well as a truly remarkable Burmese cultured pearl necklace that was the product of decades of labor (figure 4).



Figure 4. Fran Mastoloni displays a triple necklace of Burmese cultured pearls (left). From the inner strand out, the strands measure 14.65 × 10.50 mm, 14.80 × 10.30 mm, and 15.30 × 10.50 mm (right). The Mastoloni family collected the pearls from 1965 to 1975 and considers this the finest cultured pearl necklace in existence. Photos by Eric Welch (left) and Robert Weldon (right).



Figure 5. The morganite carving on the left was inspired by the floating watches in the famous Salvador Dali painting “The Persistence of Memory.” The geometric carvings on the right look simple when the stone is viewed from the base but produce an array of bright reflections and crystalline brilliance when viewed from above. Photo by Eric Welch; courtesy of Sonja Kreis.

Mastoloni added that the cultured pearl industry has become much more competitive. Dealers require much more breadth of inventory: Simply having akoya or Chinese freshwater material is no longer enough. Customers are more educated and driven to seek out unique, striking pieces of different colors, shapes, or lengths—and want to see new variations and combinations every time they look to make a purchase.

Duncan Pay

Exceptional gem artistry in sunstone, rutilated quartz, and beryl. At the GJX show, Sonja Kreis (Unique Jewelry, Niederwörresbach, Germany) displayed exceptional examples of the jeweler’s and gem carver’s art. Kreis designs the jewelry, and her son Alexander cuts the gems.

Alexander Kreis explained that their family has a tradition of over 500 years of gemstone cutting and jewelry manufacture. He apprenticed as a traditional gem cutter, but elected to find his own path to unlock the beauty of



Figure 6. The Oregon sunstones in this fantasy-cut pendant and ring, displaying deep red color and intense stripes of schiller, were cut from the same piece of rough. Photo by Eric Welch; courtesy of Sonja Kreis.

fine gem crystals. His cutting is a spectacular blend of freeform curves and dramatic geometrical cuts. Alexander works with many materials, including tourmalines and beryls (figure 5), but Oregon sunstones (figure 6) and rutilated quartz (figure 7) are among his favorites. The fine Oregon sunstone was on display at their booth. Alexander's father, Stefan Kreis, described their very strict criteria for selecting rough. On a visit to a set of mines in Oregon's Rabbit Basin, they selected 395 grams of rough out of the 50 kg they were shown; one such piece of rough is featured in figure 6.

Duncan Pay

Fine Australian chrysoprase rough and carvings. Mary Lou Osmond (Candala Chrysoprase, Marlborough, Australia) explained the nature and operation of the company's chrysoprase chalcedony mine. Mine access requires flying to the town of Rockhampton, 635 km (394 miles) north of



Figure 8. Mary Lou Osmond demonstrates the rich, vibrant color of Marlborough chrysoprase, which is due to high concentrations of nickel. Photo by Eric Welch.

Brisbane, followed by a two-hour drive in a four-wheel-drive vehicle. The site, protected with guard dogs and fences, is adjacent to a Chinese-owned mine, the only other operation in the area.

Highly translucent, deep-color chrysoprase (figure 8) is recovered from veins two to eight inches in thickness. Osmond said the bright green color of material from this deposit is due to high nickel content, reportedly up to 2.35%.

Osmond explained that most material is found after heavy rain, when the extensively mined terrain shifts. Moving water from intense storms might carry automobile-sized rocks over hills and deposit them in neighboring stream beds kilometers away. The downpours expose everything, even material that the miners have been walking over for years. After every rainstorm, it pays to scour the newly exposed ground and look for glints of green, in case there is a larger vein underneath.

Recovered material is brought back to the mining camp

Figure 7. Left: Alexander Kreis displays one of his unique pieces: a star-shaped rutilated quartz. Right: This superb 442.78 ct faceted Brazilian quartz with rutile inclusions is typical of Kreis's art. According to Kreis, the orientation of the needles is the most important decision in the design of the finished gem. Photos by Eric Welch (left) and Robert Weldon (right); courtesy of Sonja Kreis.





Figure 9. These chrysoprase carvings are from Candala's Queensland mine. Photo by Eric Welch.

for washing. Water tanks collect the rainfall, and the miners use high-pressure hoses to wash off the rough chrysoprase, which is then handpicked. The best material, marked "premium," is sent to Sydney for sale, while the remainder is sorted into four grades by color and clarity (A through D). For Tucson, Osmond brought over 80 kg of rough, of which 10 kg was premium quality.

Most buyers gravitated to the top-quality material, all of which was sold, along with over half of the A-grade material. Although buyers bought many carvings (figure 9), to Osmond's surprise they also purchased large quantities of calibrated goods. Many also sought out top-quality rough for cabochon cutting, rather than gem carvings, indicating a growing awareness and demand for the gem.

Candala's client base includes Indian, German, U.S., and Thai buyers. At this year's Tucson show, most of the chrysoprase carvings went to collectors, as well as one television shopping channel.

Duncan Pay



Figure 11. This heated 33.16 ct emerald-cut royal blue sapphire is from Sri Lanka. Photo by Robert Weldon; courtesy of B&B Fine Gems.

Fine corundum, Paraiba tourmaline, and alexandrite. At the AGTA show, Dave Bindra (B&B Fine Gems, Los Angeles) showed us an exceptionally large fashioned alexandrite reportedly from Sri Lanka (figure 10). According to Bindra, it is very difficult to find fine specimens over 5 ct, although Sri Lanka and Madagascar are known to produce sizeable alexandrite crystals. At over 100 ct, this is certainly one of the largest our team has seen. Bindra speculates that the original crystal may have been over 300 ct.

Also on display was a royal blue emerald-cut Sri Lanka sapphire weighing over 33 ct (figure 11). Bindra noted that supply of fine sapphire, while scarce, is currently stronger than fine ruby. Compared with rubies of equivalent price, fine sapphires offer more size and quality; as a result, prices have risen dramatically over the last two years. This is a function of constricted supply and increasing demand as the Chinese market opens up to premium goods. Only three to five years ago, the strongest demand from Chinese buyers was for mid-range to commercial material. The Chinese are



Figure 10. This remarkable 112.82 ct Sri Lankan alexandrite, seen under incandescent (left) and fluorescent lighting (right), is unusually large. Photos by Robert Weldon; courtesy of B&B Fine Gems.



Figure 12. Fine rubies were scarce and expensive at the 2014 Tucson gem show. According to the dealer, this 9.10 ct Mozambique ruby had only undergone low-temperature heating. Photo by Robert Weldon; courtesy of BeB Fine Gems.

currently consuming the finer items once sought only in Western Europe, the United States, and Japan. As a result, U.S. dealers and consumers have to contend with competition in this market. As Bindra pointed out, this creates “a very interesting dynamic.”

Also at the B&B booth was a superb 9 ct Mozambique ruby (figure 12), one of the finest rubies Bindra has seen from this source. He explained that Mozambique’s rubies are so popular because they come in large, strongly colored crystals; once cut, they produce clean, attractive gemstones. They are very marketable because consumers readily appreciate their beauty. Bindra told us that Mozambique ruby crystals can be a little flat, which constrains the depth of fashioned stones. It is difficult to find a piece of rough above 4–5 ct with fine color suitable for cutting a clean gemstone; this makes the 9 ct ruby exceptional. A gem of this quality might sell for US\$50,000 per carat or more.

By comparison, Burmese rubies are increasingly difficult for domestic dealers to obtain due to the U.S. embargo

against Myanmar. Trade is limited to gems that predate the ban and were already in circulation in the United States.

Finally, Bindra showed us what he described as the star of his show: a 14.59 ct Brazilian Paraíba tourmaline, reportedly unheated (figure 13). He was fortunate enough to acquire this stone out of a collection. The previous owner had purchased it years ago when the material first came out, making this another example of recirculation rather than current production. Bindra confirmed the importance of the secondary gem market, which has become critical to dealers because there is so little material coming from deposits. With so much competition at the source—especially when a deposit, such as Paraíba, is reportedly depleted—dealers have no choice but to look in the secondary market.

Duncan Pay

Fossilized drusy shells. Tarun Adlakha (Indus Valley Commerce, New Delhi) exhibited fossilized shells replaced by chalcedony and encrusted with drusy quartz (figure 14). The shells are originally from a rare left-hand coil variety of gastropod that lived between 50 and 100 million years ago, when the Indian subcontinent was submerged under the ocean. Recovered from a hill in the Dhar region of Madhya Pradesh state in central India (figure 15), they were hammered, chiseled, and carefully removed by hand from rock.

According to Adlakha, these shells were called *Dakshinavarti* in ancient Sanskrit. The Hindu, Buddhist, and Tibetan cultures revere the left-hand coil gastropods for their metaphysical powers. Adlakha has trademarked this fossilized material as Spiralite Gemshells for use in jewelry.

Robert Weldon

Gem crystals. At the Pueblo Show, Steve Ulatowski (New Era Gems, Grass Valley, California) told us how the dynamics of his business have shifted from facet-quality rough to crystal specimens, which now make up more than 80% of his turnover by dollar value. In particular, small gem crystals in wire-wrapped jewelry now form a large part of his commerce.



Figure 13. Dave Bindra shows off a superb 14.59 ct oval faceted Brazilian Paraíba tourmaline. Gems of this quality above 1 ct are extremely rare, making this gem exceptional. Photos by Eric Welch (left) and Robert Weldon (right); courtesy of BeB Fine Gems.



Figure 14. A conglomerate of fossilized, drusy quartz-encrusted shells is shown in the host rock, along with several individual pieces that have been prepared for jewelry use. Photo by Robert Weldon/GIA; courtesy of Indus Valley Commerce.

Ten years ago, facet rough made up 90% of New Era's business, while gem crystals were a mere 5%. Facet rough now represents just 10% of his total, because it is nearly unobtainable.

As an example of changing market dynamics, Ulatowski showed us a fine tanzanite crystal (figure 16), which previously would have been more valuable as a mineral specimen. In today's frenzied market, such a crystal might be worth \$45,000 uncut but command \$50,000 as rough for faceting.

Figure 15. These fossilized drusy shells were found in rocks on a hill in central India. Photo courtesy of Tarun Adlakha.



Figure 16. Tiny calcite crystals adhering to the surfaces of this superb tanzanite crystal, along with the brown coloration around its base, are strong indicators that the material has not been heated. The crystal weighs 500.45 ct and measures approximately 8 cm in length. Photo by Eric Welch; courtesy of New Era Gems.

According to Ulatowski, the criteria for a superior gem crystal include luster, color, and the condition of its edges (absence of nicks or chips). Whether or not it has a perfect termination also plays a role. Another consideration is the potential amount of cuttable material. For example, a 109-gram tanzanite crystal might yield 80 grams (400 carats) of cutting material, which would yield on average about 160 carats of fashioned gems.

Ulatowski noted that due to demand for cutting rough in late 2013, many crystals were broken for that purpose. Fine, well-formed crystals once commanded a premium over those suitable only for cutting fashioned gems; a fine crystal might be worth twice as much if left as a specimen. Although fine crystals are exceptionally rare, the market for cutting rough is tremendous right now, with worldwide shortage of every type of cutting material—even staples like blue topaz and smoky quartz. He has never seen a rough shortage comparable to this current one. Like other dealers at the shows, Ulatowski believes this represents a combination of less global mining activity, stricter mining regulations in many countries, rising fuel costs, and growing Asian demand.

Still, his U.S. client base is reluctant to pay higher prices for what they perceive as overpriced rough. There is also a growing trend toward better cutting at the source, with governments trying to support their own domestic cutting industries, as this retains more value in country than merely exporting the rough as raw material.

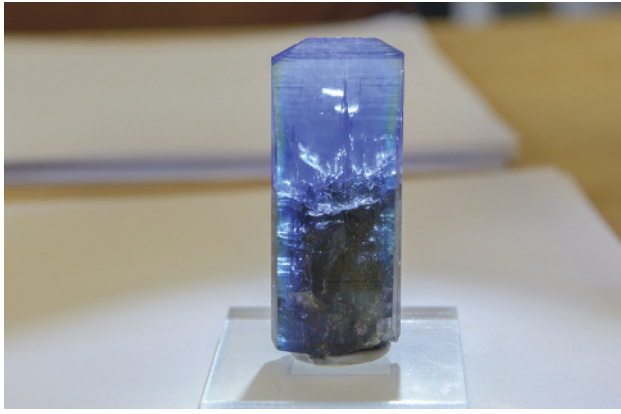


Figure 17. This 335.46 ct crystal contains relatively little cuttable material, but its crystal form and condition are excellent, making it worth five times more as an uncut specimen. The cuttable portion is located near the tip of the crystal, where the rough begins to narrow, so there is not enough depth for a significant faceted stone. Photo by Eric Welch; courtesy of New Era Gems.

Ulatowski had a range of unheated tanzanite crystals, which he estimated might make up 20% of total rough tanzanite production. He showed us many examples with blue to green terminations and brown coloration near the base (figure 17). A few blue crystals included calcite matrix, while some had associated pyrite.

Although many in the trade say all blue tanzanites have been heated, Ulatowski explained that it is impossible to heat only part of a crystal. Therefore, any crystal that is brown on the base has not been heated. In many speci-

Figure 18. This 765.00 ct tanzanite crystal was heated in an oven at approximately 1000°F to remove all brown coloration. After the temperature was raised incrementally over a number of hours, the peak temperature was maintained for one hour before gradual cooling over a period of six to eight hours. Prior to heating, the crystal was completely brown, with no traces of blue. Photo by Eric Welch.



Figure 19. Specimen crystals, such as this 87.59 ct natural-color unheated reddish brown zoisite, are currently the mainstay of Steve Ulatowski's business. Photo by Eric Welch; courtesy of New Era Gems.

mens, the brown base is best for cutting, as it is usually the widest part of the crystal.

Demand for what Ulatowski calls "fancy tanzanite" (zoisite) is strong, with top pink colors selling for up to \$800 per carat. Unheated natural pinks usually form only in the tip of the crystal, so most stones are small (less than a carat). The most valuable specimens are pure pink, with no purple cast.

For contrast, Ulatowski showed us a heated crystal where the brown coloration had been removed (figure 18), as well as a natural unheated reddish brown sample (figure 19) with no hint of blue. He also had a range of green grossular garnet crystals, a byproduct of Merelani tanzanite mining (figure 20). Also remarkable were bicolor tourma-

Figure 20. In Merelani, green grossular garnet (tsavorite or "mint" garnet) is a byproduct of tanzanite mining. This unusual 27 ct group of intact euhedral crystals measures approximately 4 cm in length. It is a "floater," meaning there is no visible attachment to any host rock. Photo by Eric Welch; courtesy of New Era Gems.





Figure 21. These bicolor tourmaline crystals are reportedly from the Barra de Salinas mine near Coronel Murta in Minas Gerais, Brazil (left). Each 2–3 cm crystal had a heavily etched, almost skeletal pink core topped by a euhedral or very slightly etched green cap. The terminations (right) may have projected into a layer of clay minerals during formation, protecting them from etching. Photos by Eric Welch; courtesy of New Era Gems.

line crystals (figure 21) with an unusual etched core but intact terminations. These were reportedly from the Barra de Salinas mine in Minas Gerais, Brazil.

In closing, Ulatowski noted that his best sales year at Tucson was 2013, but that 2014 was headed in the same direction.

Duncan Pay

Varieties of rutilated quartz. Rutilated quartz has come into its own as a mainstream gem material, thanks in part to its seemingly infinite variety and one-of-a-kind appeal for jewelry designers. Reddish rutile, owing its color to traces of iron, was exhibited at the AGTA show by Rare Earth Mining Co. (Trumbull, Connecticut). Rare Earth CEO Bill

Figure 22. This 85 ct quartz crystal contains bright reddish rutile needles. Photo by Robert Weldon; courtesy of Rare Earth Mining Co.



Heher said the material was recovered from Bahia in northern Brazil some decades ago before the mine closed. But due to the rising value of rutilated quartz, the deposit has been reopened and worked in recent years. The distinctiveness of the material, in this case an 85 ct gem (figure 22), lies in its relative transparency and bright reddish color—which can be matched or contrasted in jewelry.

Golden and copper-color rutile is traditionally seen in quartz, and connoisseurs are always on the lookout for a six-rayed star pattern of rutile. Though such stars occur regularly in the rock crystal, they are rarely oriented in such a way to be easily cut into a faceted or cabochon gem. Strong, isolated rutile stars located in the rough must be painstakingly oriented to be visible face-forward, as in the 34.55 ct gem (figure 23) cut by Falk Burger (Hard Works, Tucson). At

Figure 23. This 34.55 ct quartz has been cut to display the star-shaped needle formation. Photo by Robert Weldon; courtesy of Hard Works.





Figure 24. This 209.06 ct quartz features a rose-shaped cluster of inclusions. Photo by Robert Weldon; courtesy of Hard Works.

the center of the star, an additional inclusion of hematite is visible.

Burger said that rutile can take unusual forms as well. Minute gray rutile needles in the top of the quartz in figure 24 are clustered in the shape of a rose. The quartz also contains layers of pink and greenish chlorite phantoms. The quartz itself weighs 209.06 ct, and was fashioned by Burger to best exhibit the rutile rose.

Robert Weldon



Figure 26. This ring's centerpiece is a euhedral 2.76 ct ruby crystal from Winza, Tanzania, flanked by a pair of Canadian rough diamonds. Two green diamonds from Venezuela complete the piece. Photo by Eric Welch; courtesy of Nature's Geometry.

Innovative optical effects, unique rings with raw crystals.

At GJX, Brian and Kendra Cook (Nature's Geometry, Graton, California) showed an innovative series of clear quartz disks they call "wheels of light." These disks are mounted in work-hardened 24K yellow gold for use as pendants or earrings. The center of each disk contains a tube where an insert of colored gem material can be placed. The tube is subsequently sealed with clear quartz. When the disk is viewed face up, the insert's color reflects and suffuses the disk with bright color (figure 25).

For red, Cook uses ruby or even realgar (also known as "ruby sulfur," a very soft arsenic sulfide mineral), and Paraíba tourmaline or haüyne (a brittle sodium calcium sulfate) for rich blues. As the insert is completely enclosed within the quartz, the materials are protected from wear.



Figure 25. "Wheels of light" are innovative quartz disks with sealed inserts of colored gems or minerals, creating multiple reflections to lend color to otherwise transparent rock crystal. Inside these examples are Paraíba tourmaline (left) and realgar (right). Photos by Eric Welch; courtesy of Nature's Geometry.



Figure 27. This ring features cat's-eye spessartine garnet with Paraiba tourmaline shoulder stones in a 24K work-hardened gold mounting. Photo by Eric Welch; courtesy of Nature's Geometry.

Cook displayed several intriguing rings with rough crystals, including ruby (figure 26), alexandrite, and diamond, also in work-hardened gold. Another standout featured a cat's-eye spessartine garnet with Paraiba tourmaline cabochons in a similar mounting (figure 27).

Duncan Pay

Mexican opal. Jorge Tamayo Carrillo (Opalos & Artesanias Mexicanas, Magdalena, Mexico) outlined current production of fire opal at his family's mine, located 10 km south of Magdalena in Jalisco, Mexico.

Tamayo said the mine was shut down several years ago. His family took a risk and reopened it, and now they have worked it for more than five years. The material they exhib-

Figure 28. This rhyolite matrix specimen contains opal-filled cavities displaying play-of-color. Photo by Eric Welch; courtesy of Opalos & Artesanias Mexicanas.



Figure 29. Deep orange and cherry red hues are more valued than lighter yellow or orange in these rough Mexican opals without play-of-color. The opals in the back row range from 25 to 107 ct, while the fashioned gems weigh 7.50–31.50 ct. Photo by Eric Welch; courtesy of Opalos & Artesanias Mexicanas.

ited at the GJX show represented several years of production.

The operation employs about 20 people. The miners look for opal-filled cavities (figure 28) in the rhyolite host rock. Veins last anywhere from two days to a few years on occasion. Explosives are used to break the host rock, and dump trucks move the ore to the surface, where workers break it up further with small hammers to extract the opal.

Production is put aside for six months to a year to minimize the risk to customers that the opals might show crazing due to water loss. At this point, Tamayo estimates, only 5% of the material might craze. Opalos & Artesanias Mexicanas has now been in business for 27 years, and the second-generation company prides itself on full disclosure. Its clientele consists of buyers in the United States, Japan, China, and Germany. All cutting is done in house or by local artisans, as the company aims to support the local community.

Red, pink, orange, yellow, and colorless ("clear" or "white") specimens without play-of-color are polished by hand into freeform shapes or used for faceted stones (figure 29). Fine material with play-of-color is fashioned into cabochons or freeform shapes (figure 30). Lower-end material—essentially rhyolite matrix with gemmy opal portions—is fabricated by hand into cabochons for use in rings, bracelets, and cufflinks.

Duncan Pay

Natural-color tanzanite and yellow sapphire. At the GJX show, Kobe Sevdermish (Advanced Quality, Ramat Gan, Israel) displayed fine unheated tanzanite (figure 31), untreated yellow sapphire, and heated pink zircon.

While it is easier to buy unusual-colored tanzanite rough today, the material still is not available in abundance. Sevdermish informed us that what he calls "fancy-color" tanzanite comes from the same area as the familiar blue to

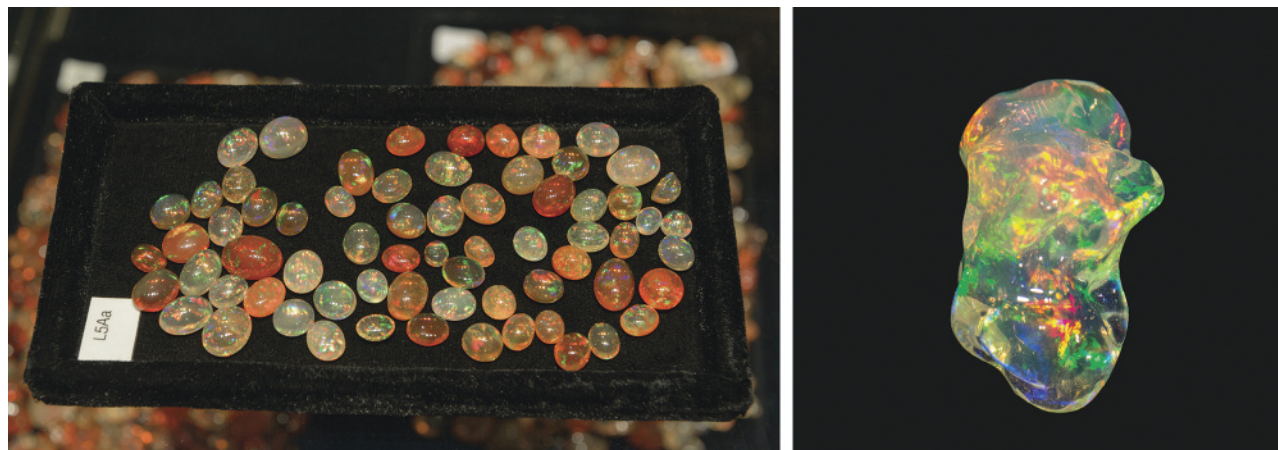


Figure 30. Top-quality material with play-of-color is cut in cabochon (left) or freeform style (right), which entails far less loss of weight from the original rough. The best material shows striking flashes of color against a colorless, yellow, or orange to red body. Photo by Eric Welch; courtesy of Opalos e Artesanias Mexicanas.

bluish purple tanzanite. The rough pieces he displayed in Tucson had greenish, golden, green blue, pink, and purplish pink colors. The rarest are greens, followed by golden hues. These stones were best sellers for the company in 2013.

According to Sevdermish, the U.S. market is full of “regular” heated tanzanite, and people are looking for something unique. Clients are especially taken with sets where each stone displays a slightly different color. In his opinion, the luster of the unheated stones is significantly better. Sevdermish ensures that no heating is performed on any of the rough he selects. All stones are polished at the company’s factory in Bangkok.

After describing a large piece of highly transparent rough that took a week to purchase, Sevdermish showed us the two significant pieces cut from it: a 50.61 ct green-

blue oval and a spectacular 19.80 ct greenish blue heart with arresting green and blue green pleochroism cut from the top part of the crystal.

He called our attention to precision-cut unheated yellow sapphires (figure 32) arranged as sets or as precisely cut calibrated shapes, including ovals, pears, and princess cuts. Sevdermish described this corundum as a “true canary color,” which is unusual in a natural-color sapphire. He said most of the strong yellow sapphire on the market is either heated or beryllium-treated.

All the rough is carefully selected for color consistency in order to avoid greenish or grayish hues. Sevdermish estimated they select about 5% of the rough production, suitable for cutting into 2–5 mm finished stones, from a small mine in Africa. Material for 0.50 or 1 ct sizes is very rare.

Figure 31. These large, reportedly unheated tanzanites possess fine color. Photos by Eric Welch; courtesy of Advanced Quality.

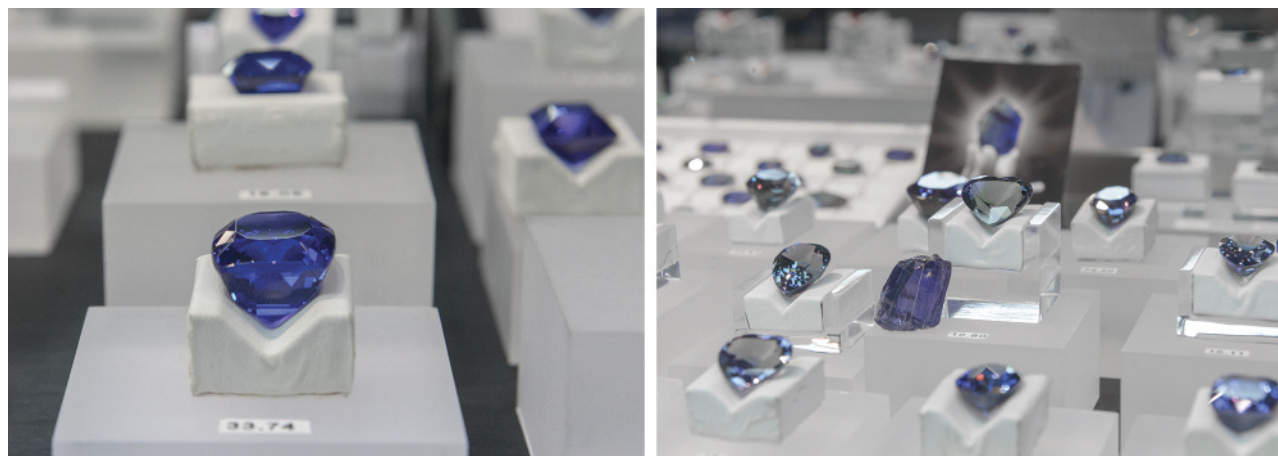




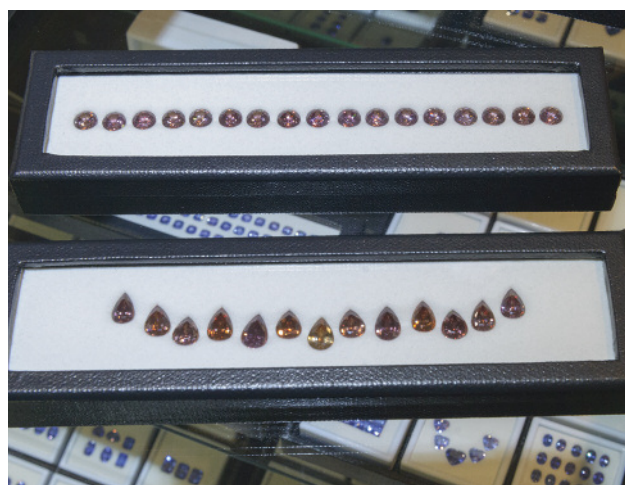
Figure 32. Precision-cut unheated yellow sapphire sold well to buyers looking for yellow diamond substitutes. Photo by Eric Welch; courtesy of Advanced Quality.

Sevdermish said his clients like the material because its clarity, color, and polish give it the look of fancy-color diamond.

Finally, Sevdermish showed us what he described as “fancy vivid” pink zircon from Tanzania (figure 33). The zircon was heat-treated, lightening the original color of the rough to reveal pinks with cinnamon tints. Further heating lightens the color a little more, producing very bright, lively stones. The only downside, Sevdermish remarked, is the name “zircon.” Customers tend to confuse the name with “cubic zirconia,” which makes them reluctant to purchase the gems until they understand that zircon is a natural stone.

Duncan Pay

Figure 33. These heated Tanzanian zircons displayed a range of warm pinkish to yellowish brown colors. Photo by Eric Welch; courtesy of Advanced Quality.



Red beryl. At the AGTA show, Ray Zajicek (Equatorial Imports Inc., Dallas) displayed matched red beryls—originally mined from Utah’s Wah Wah Mountains—as suites of jewelry and in loose stone form. According to Zajicek, these gems represent newly marketed inventory cut by Colombian cutters in Gibraltar between 1998 and 2000. Each suite contained 25–30 carats of matched red beryls as emerald, marquise, or oval cuts (figure 34).

Zajicek, who began working with red beryl in the 1980s, said the average faceted gem is approximately 0.08 ct. A 0.50 ct sample would be large, and anything above a carat would be exceptionally rare. This made the matched

Figure 34. This matched suite contains 27.35 carats of faceted oval red beryls. Photo by Eric Welch; courtesy of Equatorial Imports.





Figure 35. Here, red beryls are mounted with benitoite from California in a pendant (left), and with 28.59 carats of unheated Yogo sapphire from Montana in a spectacular necklace (right). Photos by Eric Welch (left) and Robert Weldon (right); courtesy of Equatorian Imports.

suites at his booth unique and potentially irreplaceable. Like emerald, red beryl has a range of hues and tones, as well as a typically uneven color distribution that makes it a challenge to match.

Zajicek said there is more red beryl in the ground, but the difficulty of mining makes future production cost-prohibitive. Previous operations had to move more than a ton of hard rock to recover a carat of rough. A carat-sized rough stone is not necessarily cuttable; yields are low, averaging between 8% and 15%.

Zajicek described red beryl as a beautiful, uniquely American product that is still relatively unknown. Intriguing combinations included a pendant comprised of red beryl mounted with benitoite (figure 35, left), and a red, white, and blue necklace featuring red beryl, Montana blue sapphires, and colorless diamond (figure 35, right).

If there were more viable red beryl mining locations in Utah, the increased production would boost demand and allow greater promotion. As it stands, few would spend money to promote a gem they probably would not be able to obtain in any quantity.

Duncan Pay

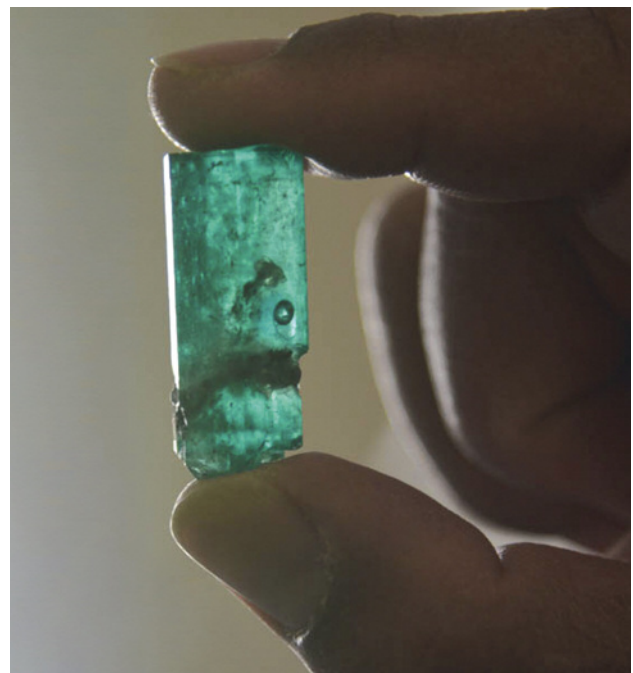
OTHER NOTABLE FINDS

More of the interesting and unusual. Among the other fascinating materials seen in Tucson were a Colombian emerald crystal with an eye-visible multi-phase inclusion (figure 36), a large nugget of turquoise (figure 37), some interesting quartz from Namibia (figure 38), and large colorful slices of liddicoatite tourmaline (figure 39).

Stone and fossil photography. At the Tucson Gem and Mineral Show, Mike Woodward (San Clemente, California) showcased a collection of stone and fossil photos (figure

40). With their variety of arresting forms, the images resemble abstract paintings or landscapes. Among the featured materials were Australian and Peruvian opal, banded agate, and ammonite. Woodward, a graphic designer by

Figure 36. This emerald crystal, reportedly from Muzo, Colombia, is approximately 35 mm long and contains an eye-visible multi-phase inclusion. The gas bubble within the inclusion moves a few millimeters as the crystal is tilted. Photo by Duncan Pay; courtesy of William Johnson, Natural Formations.



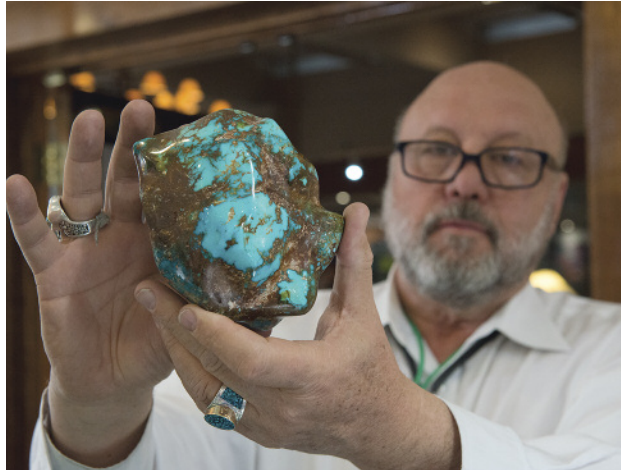


Figure 37. This spectacular 7,043 ct turquoise nugget was recovered from the Lavender Pit mine of Arizona in 1934. Lavender Pit was adjacent to the much larger Bisbee copper mine. Much of the turquoise from Arizona's mines was reputedly smuggled out by copper miners, and thus referred to as "lunch bucket" turquoise. Photo by Eric Welch, courtesy of Studio GL.

trade, has collected stones since the age of five, and has photographed them for 12 years. The images are captured with a 4 × 5 camera, using a polarized macro lens and a high-resolution digital camera back. They are enlarged as

Figure 38. These curious examples of "crazy quartz" are reportedly from basalt cavities in the Gobobos Mountains of Namibia. These well-formed colorless quartz crystals are capped by smaller amethyst-colored tips in a "reverse scepter" formation. The crystal cluster is approximately 6 cm wide. Photo by Eric Welch; courtesy of Stefan Reif, Reif Collection.



Figure 39. These slices of liddicoatite tourmaline display colorful growth zoning. The largest slice measures approximately 30 cm. Photo by Duncan Pay; courtesy of Frederic Gautier, Little Big Stone.

single panels, or triptychs, and available in a variety of formats, including canvas, aluminum prints, and traditional photographic prints.

Stuart Overlin

Figure 40. This enlarged image of a Peruvian opal showcases the dramatic forms captured by Mike Woodward. Courtesy of Mike Woodward Photography.



REGULAR FEATURES

COLORED STONES AND ORGANIC MATERIALS

Gem-quality Cr-rich kyanite from India. In 2009, one of the contributors had the opportunity to see small lots of greenish blue to bluish green Cr-rich kyanite in Jaipur, reportedly mined from the eastern Indian state of Odisha (formerly Orissa). Most of the cabochons and faceted gems, ranging in size up to 25 ct, were highly included. In 2013, this Cr-rich kyanite from Odisha was again available in Jaipur, this time with very few or no eye-visible inclusions (figure 41). Although a few specimens contained numerous black inclusions, most of the stones lacked these features and had a more desirable uniform greenish blue to bluish green color, making them suitable for jewelry mounting.

Standard gemological properties were measured for one cabochon and two faceted samples (0.99–6.17 ct). The cabochon was chosen for its striking black eye-visible inclusions. The three samples showed an RI of 1.714–1.730 (spot RI of 1.73 for the cabochon) with birefringence of 0.016 and a biaxial positive optic sign, and a hydrostatic SG of 3.68–3.70. Moderate to strong trichroism was observed, with pleochroic colors of greenish blue, bluish green, and pale green. Under a desk-model spectroscope, all three displayed fine lines in the red region with absorption bands in the yellow-orange and blue regions. The samples appeared strong red under the Chelsea filter and were inert to both long- and short-wave UV. These properties were consistent with those reported for kyanite.

Examined under the microscope, the black inclusions in the cabochon appeared to be clusters of black grains with striated surfaces and metallic luster (figure 42); some ap-

Figure 41. These gem-quality kyanites (0.99–6.17 ct) were reportedly mined in the eastern Indian state of Odisha. Photo by Gagan Choudhary.

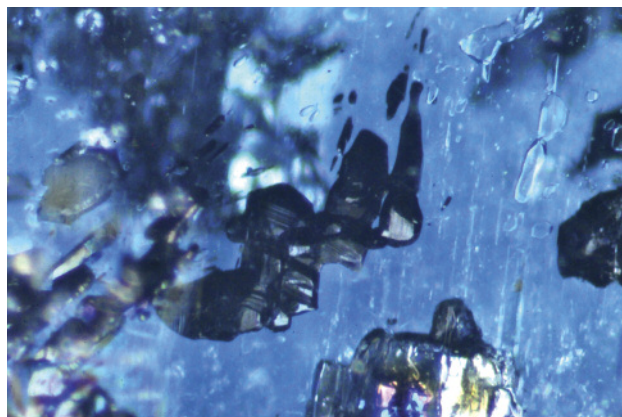
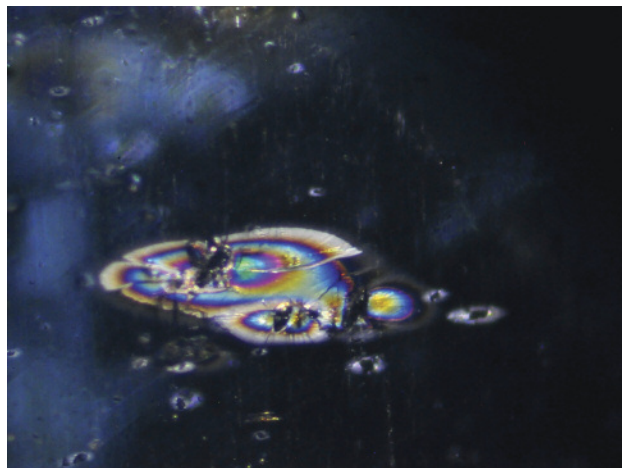


Figure 42. These kyanites display striking black metallic crystals of ilmenite; note the striated surface and the few colorless crystals of quartz. Photomicrograph by Gagan Choudhary; magnified 64x.

peared iridescent in reflected light, while others displayed frosted surfaces. Raman and SEM analysis identified these black grains as ilmenite. In addition, numerous colorless sub-rounded crystals of quartz, feldspar, and zircon were observed; the latter usually occurred in clusters, with stress cracks around them (figure 43). These samples also displayed cleavage planes in two directions and fine fissures, a characteristic usually seen in kyanites.

UV-Vis-NIR spectroscopy in the 300–800 nm region (figure 44) showed broad absorption bands between 500 and 700 nm, with a slight shift in the center position from about 585 nm (green direction) to 610 nm (blue direction). Also present were distinct peaks at approximately 370, 380, 417, 432, 446, 690, and 708 nm. The latter two peaks

Figure 43. Clusters of zircon crystals associated with stress cracks were another common feature in these kyanites. Photomicrograph by Gagan Choudhary; magnified 80x.



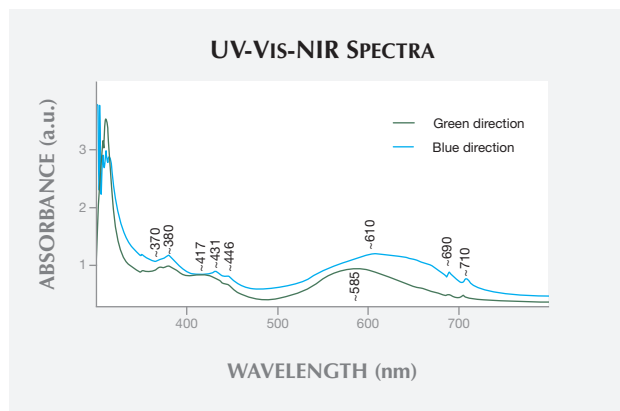


Figure 44. The UV-Vis-NIR spectrum in the 300–800 nm region showed broad absorption band between 500 and 700 nm (assigned to Fe^{2+} - Ti^{4+} charge transfer), along with twin peaks at approximately 690 and 708 nm (associated with Cr^{3+}). In addition, numerous Fe^{3+} -related peaks were present in the 350–470 nm region.

are associated with Cr^{3+} and the rest to Fe^{3+} . The broad absorption band is attributed to the Fe^{2+} - Ti^{4+} charge transfer (see G. Bosshart et al., “Blue colour-changing kyanite from East Africa,” *Journal of Gemmology*, Vol. 18, No. 3, pp. 205–212).

Gem-quality kyanite is already known from Nepal, Brazil, Kenya, Tanzania, and Madagascar (the latter material being Cr-rich as well). Now India can be added to this list, with attractive greenish blue to bluish green colors. The production and supply of this kyanite are still unknown.

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Indian ruby mining. The Karur-Kangayam and Hole-Narsipur belts, in the southern Indian states of Tamil Nadu and Karnataka, respectively, are famous throughout the subcontinent for their gemstones, including sapphire, moonstone, iolite, aquamarine, garnet, sunstone and corundum. The city of Karur itself is well known for rubies. Ruby is also found in Subramaniam (also known as Red Hills), near Madikeri in Karnataka. Channapatna (figure 45, top left), roughly 280 km (117 miles) from Madikeri, is famous for its star rubies. In all of these locations, mining is performed using primitive methods.

Good-quality transparent rubies come from the Karur region, though color varies along this gemstone belt. The mines situated in Karur are located on barren land along the roadside; the nearby towns of Kangayam and Paramatti also have ruby mines.

Madikeri is a remote hill station covered by lush green forests, located in the Western Ghats of India. The ruby found here is lighter, translucent to transparent, and of

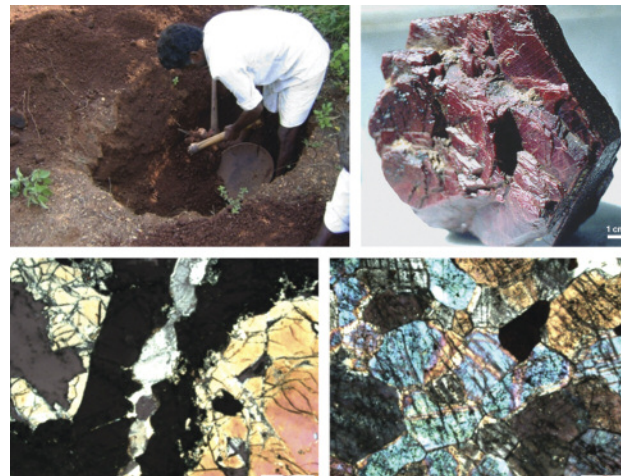


Figure 45. Top left: Rubies are mined in a mango orchard in Channapatna, India. Top right: This 15 kg rough ruby is from Subramaniam, in the Indian state of Karnataka. Photos by Pooja Shirole. Bottom left: This thin section of ruby is surrounded by an isotropic reaction rim. Bottom right: A corundum granulite showing ruby with blue and pink interference colors. Photomicrographs by Pooja Shirole; crossed polarizers, magnified 4 \times .

good quality. A ruby-bearing granulite, commonly called ruby rock, is used for making artifacts such as wands and crystal balls.

In the town of Subramaniam, close to Madikeri, large hexagonal pillars of ruby are mined; deposits are also located in the nearby villages. The stones are mainly hexagonal but come in many sizes and shapes. They have a maroon color, and some show 16 mm dot inclusions of hematite. These rubies range from 20 to 100 mm across the pinacoidal face, with the length across the prism faces varying from 10 to 50 mm. Their weight ranged from 10 g to 2 kg, though specimens are as large as 15 kg, as in the top right image in figure 45.

In the Bangalore district of Karnataka, opaque maroon star ruby is found in the village of Channapatna and other nearby villages. It is extracted from red and yellow soils in mango and coconut orchards, rather than from traditional mines.

Granulite, the host rock of the Karur rubies, is somewhat similar to the host rock of Mozambique rubies (see Winter 2012 GNI, pp. 309–311). Both contain hornblende, biotite, and plagioclase. In certain areas such as Sengal and Kiranur, rubies are found in association with gem-quality iolite (cordierite). The ruby in Pamakondampalayam is found with a reaction rim of spinel, sapphirine, and cordierite (figure 45, bottom left), while the Madikeri rubies are associated with plagioclase, augite, garnet, sillimanite, and sphene in corundum granulites (figure 45, bottom right). Madikeri ruby also occurs in corundum-

fuchsite-mica schists, which have a mineral assemblage of fuchsite mica, quartz, corundum, and rutile.

In summary, good-quality transparent ruby comes from host rocks in Karur; tabular hexagonal crystals ranging from transparent to translucent are mined from corundum granulites in Madikeri; and opaque star-ruby is found in the mango and coconut orchard soils of Channapantna.

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Large oolitic opal block. Longtime opal dealer Tibor Shelley (Opals by GMT, Adelaide, Australia) recently brought a large 1.43 kg block of opal (figure 46) to GIA's Carlsbad laboratory for examination. Mr. Shelley said he purchased it from a miner at the Andamooka opal fields in Australia more than 40 years ago. Since then, it has remained in his private collection. The RI measured on the polished face of this sawn and partially polished block was 1.45, consistent with opal.

Upon initial observation, the semi-translucent to opaque opal appeared similar to typical matrix-type opal from Andamooka that is routinely treated black. Microscopic examination, however, revealed an interesting and unique texture rarely seen in Andamooka opal. The stone was composed of numerous dark spherical inclusions, known as "oids," with precious opal filling in the pore spaces between the spheres (figure 47). This type of opal has been previously re-

Figure 46. This exceptionally large 1.43 kg block of opal, which measures 12.8 × 10.1 × 5.8 cm, is rare not only for its size but also its oolitic texture. Photo by Robison McMurtry; courtesy of Tibor Shelley/Opals by GMT.

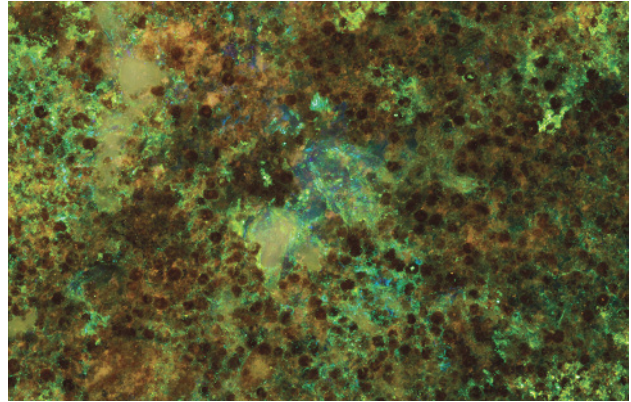
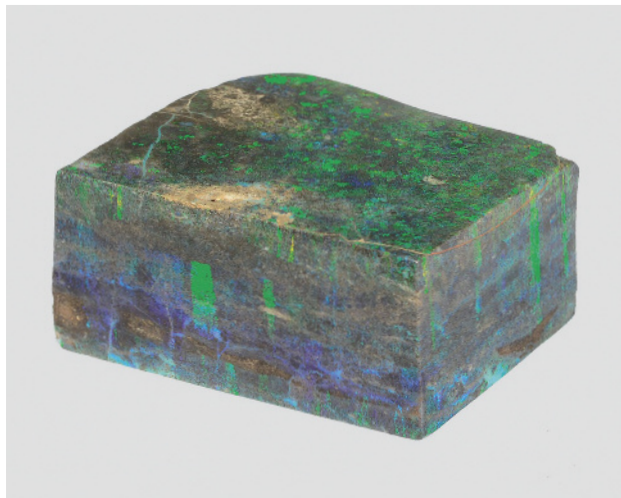


Figure 47. Numerous brown spheres scattered throughout precious opal were seen in this very large block of oolitic opal from Andamooka, Australia. Photomicrograph by Nathan Renfro, courtesy of Tibor Shelley/Opals by GMT; field of view 17 mm.

ported (see Summer 1982 Lab Notes, p. 104; Winter 1984 Lab Notes, p. 229; and Spring 1986 Lab Notes, p. 50), but this example is especially rare due to its large size. Although an example of treated black oolitic opal has also been previously reported (Spring 1983 Lab Notes, p. 46), microscopic examination revealed that the overall gray bodycolor of this extremely large opal was due to the high density of dark ooids scattered throughout the block. There were also some light brown patches that appeared to be a sandstone type of matrix, as well as numerous veins and pockets of precious opal that did not contain ooids.

This unusual piece of natural-color oolitic opal is the largest of its type that GIA has examined to date.

Nathan Renfro
GIA, Carlsbad

Natural pipi pearls from Tahiti. Recently, the Laboratoire Français de Gemmologie (LFG) received a parcel of nearly 100 pearls submitted as natural pearls from *Pinctada maculata*. The owner (Bruno Arrighi, Croissy Pacific) specified that he had personally collected the parcel in French Polynesia during the past year (figure 48).

Pinctada maculata is a bivalve mollusk (figure 49) found in the Pacific Ocean, particularly near French Polynesia and the Cook Islands, that may produce rare "poe pipi" (better known as "pipi") pearls. There were several unsuccessful attempts in the 1950s to produce cultured pipi specimens. Today, all such pearls are considered natural.

Different techniques are used to find the pearls. In one method, divers pick the largest shells of *Pinctada maculata*, then leave the shells on the beach in buckets full of salt water to putrefy. Three days later, the shells are selected and only the valves with blisters are kept. Deep in the bucket, one may occasionally find a few natural pearls. *Kakaro* (in the Paumotuan language) is considered the oldest technique

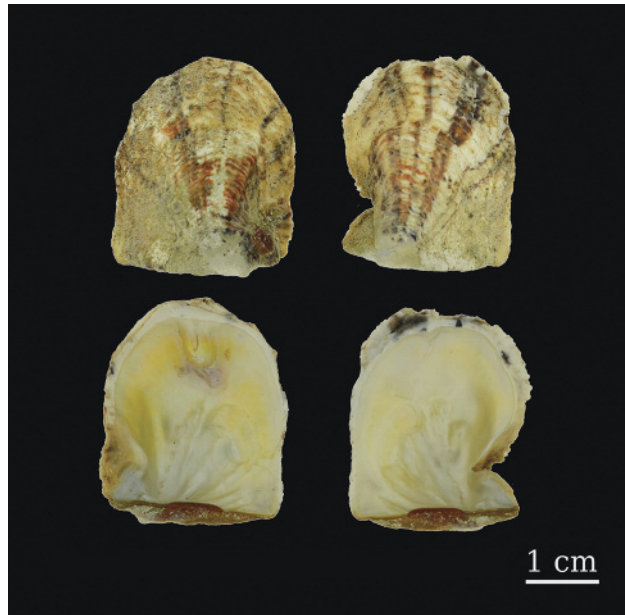


Figure 48. This parcel of rare natural pipi pearls was collected from French Polynesia. Note the exceptional golden pearl in the front with a diameter of 9.6 mm, believed to be the largest recorded pipi pearl. Courtesy of Bruno Arrighi/Croissy Pacific. Photo by Olivier Segura.

for obtaining pipi pearls. During the dive, the largest shells are opened directly underwater to locate pearls.

Most pipi pearls range from orange to cream, gray, and white, but the typical and most sought-after color is a deep

Figure 49. The two valves of a typical *Pinctada maculata* shell specimen (interior and exterior view). Photo by Olivier Segura.



golden color. The size of the pearls generally ranges from 1 to 4 mm. The pearl in the forefront of figure 49 has one of the best golden colors possible. It is an exceptionally large specimen measuring 9.6 mm in diameter, which the contributors believe to be the largest size documented for a pipi pearl.

Microradiography reveals internal structures typical for natural pearls: onion-like stacking of aragonite layers possibly containing a calcitic core. Although Raman scattering, UV-visible reflectance, or UV luminescence spectrometry have helped identify the mollusk species in some cases, preliminary results with *Pinctada maculata* are still not conclusive. Hence, it is not possible to identify with certainty the exact mollusk from which these pearls came.

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TREATMENTS

Polymer-impregnated aventurine quartz, a new imitation of “ice jade.” The market for jadeite jade is sizable, especially in the Far East. The variety and quantity of jadeite imitations is vast, a source of concern for the trade and consumers alike. A client recently submitted a polymer-impregnated aventurine quartz bangle to the Lai Tai-An Gem Lab in Taipei under the mistaken impression that it was jadeite jade.

The 212.90 ct bangle measured approximately 68 × 13 mm and exhibited a light green color, with a pleasant semi-transparent appearance that resembled a type of jadeite

Figure 50. This light green semi-transparent bangle was made from polymer-impregnated aventurine quartz, a new imitation of “ice jade.” Photo courtesy of Lai Tai-An Gem Lab.



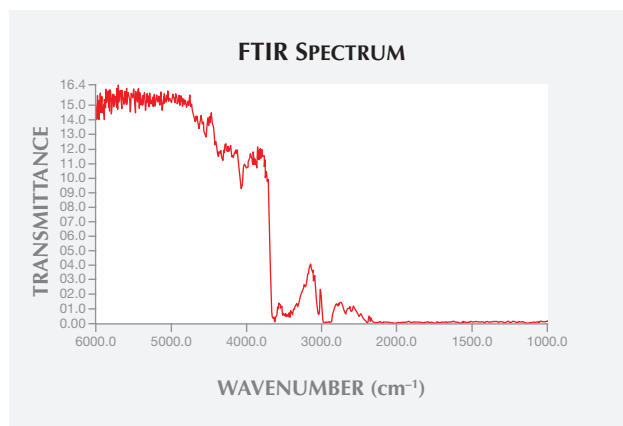


Figure 51. FTIR testing of the bangle revealed polymer impregnation at the 3000–3100 cm^{-1} absorption in the mid-infrared region.

often referred to as “ice jade” (figure 50). Standard gemological testing gave a spot RI of 1.54 and an SG of approximately 2.66, and we observed inclusions of fuchsite mica, properties all consistent with aventurine quartz. More advanced methods, namely FTIR and Raman spectroscopy, were also applied. The FTIR spectrum (figure 51) revealed the polymer treatment of the piece. The long-wave UV light reaction was a very strong blue (figure 52), which appeared to confirm the treatment. Natural aventurine normally has an inert to weak reaction to long-wave UV light; by contrast, polymers generally show a moderate to very strong blue reaction. The acid-damaged surface structure observed with a microscope also corresponded with the treatment procedures used on jadeite.

In our experience, polymer-impregnated aventurine quartz is rarely encountered in the jewelry market. Still, its resemblance to “ice jade” shows that buyers should be fully aware of the potential risk of misidentifying such material.

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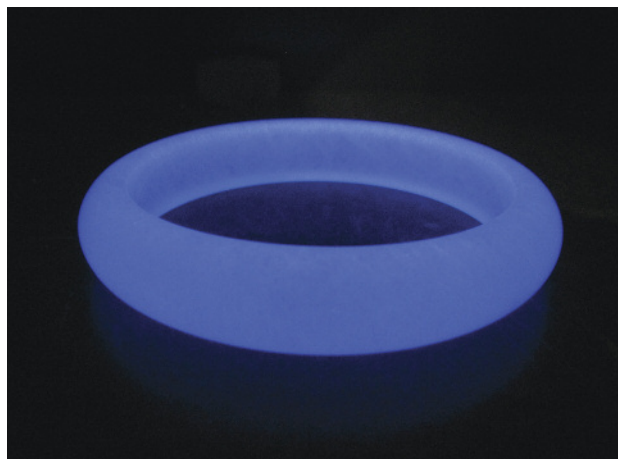
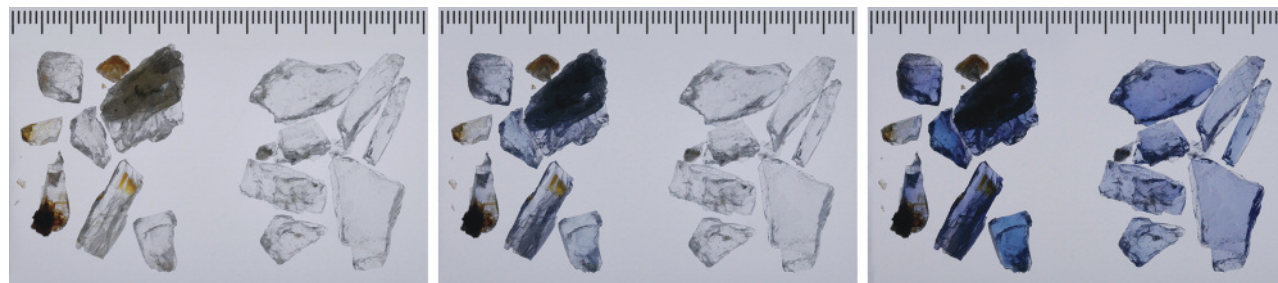


Figure 52. Notably, the bangle had a very strong blue reaction to long-wave UV light. Photo courtesy of Lai Tai-An Gem Lab.

Tenebrescent irradiated scapolite. Sixteen near-colorless scapolite rough crystal fragments, provided by Dudley Blauwet (Dudley Blauwet Gems, Louisville, Colorado) were recently examined in the Carlsbad laboratory. All of the samples were reportedly from the Pitawak mine in the Sar-e-Sang region of Afghanistan’s Badakhshan province. The material was transparent and near colorless, with transparent crystal and fluid inclusions, and some brownish epigenetic staining in cracks.

Half of the crystals had reportedly undergone radiation treatment. The identification of both the natural and irradiated groups as scapolite was confirmed with Raman spectroscopy. Both sets of crystals appeared the same under normal lighting conditions (figure 53, left). When exposed to long-wave ultraviolet (LWUV) light, both the natural and artificially irradiated scapolite showed a strong yellow fluorescence, which was slightly less intense in the irradiated

Figure 53. The scapolite pieces on the left side of these photos were irradiated, while the right group of scapolite fragments were not. The photo on the left shows the scapolite before exposure to UV radiation. In the center photo, the scapolite has been exposed to LWUV for 10 minutes. The photo on the right shows the samples after 30 seconds of exposure to SWUV. Scale is in 1 mm increments. Photos by Nathan Renfro.



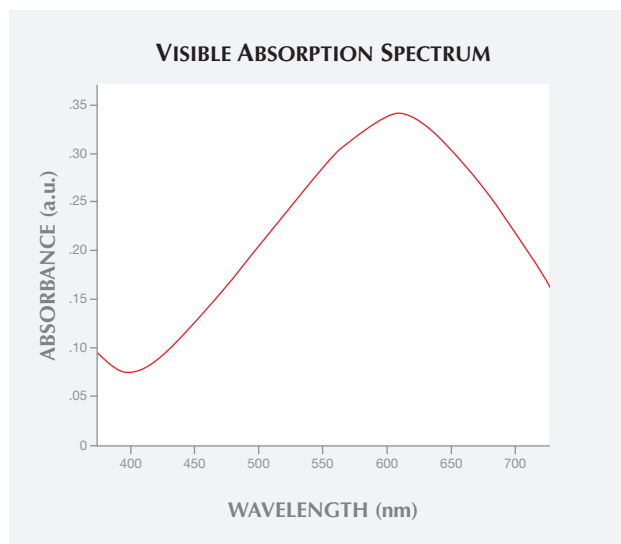


Figure 54. The visible absorption spectrum of the blue color-causing tenebrescent defect showed a broad absorption band centered around 610 nm. The transmission window in the blue region is consistent with the observed blue color.

scapolite. Under short-wave UV light (SWUV) a similar intensity trend was observed, with both the natural and artificially irradiated scapolite fluorescing a weak to moderate yellow. However, the most notable difference was in the intensity of the tenebrescent effect exhibited in both sets of stones, which occurs after exposure to both LWUV and SWUV light sources.

Tenebrescence is the phenomenon that occurs when a mineral changes color after exposure to UV light. The color change is temporary, and can be reversed when the material is exposed to incandescent light. Tenebrescence in natural scapolite has been documented (Fall 2005 GNI, pp.

Figure 55. This 4.27 ct sapphire was filled with orangy yellow lead glass throughout the stone. Photo by Gagan Choudhary; courtesy of Dheeraj Gupta.



269–271). In the case of these 16 scapolite samples, tenebrescence was observed as a moderately saturated blue color in a previously near-colorless stone. Based on the submitted materials tested, it appeared that artificially irradiating scapolite created a much stronger tenebrescent effect when the material was subsequently exposed to UV light. The material displayed tenebrescence when subjected to LWUV, but the intensity was generally greater after exposure to SWUV (figure 53, center and right). After exposure to SWUV, the visible absorption spectrum of the blue color-causing defect was measured. The resulting visible spectrum confirmed that the blue color was induced in the scapolite (figure 54).

Irradiation of colorless scapolite appears to have a very limited effect on the material. After performing various gemological tests, the only significant difference we observed was the strength of the tenebrescence, which may serve as a clue that the scapolite was previously irradiated. The appearance of the material was otherwise not improved in any noticeable way.

Tara Allen, Nathan Renfro, and David Nelson
GIA, Carlsbad

Yellow sapphire filled with lead glass. This contributor has previously reported glass-filled, color-changing red and blue corundum (Spring 2008 GNI, pp. 88–89). After recent reports of green sapphire filled with lead glass (Fall 2013 Lab Notes, p. 176) and sapphires with cobalt-colored lead glass (e.g., T. Leelawatanasuk et al., “Cobalt-doped glass-filled sapphire; an update,” *Australian Gemmologist*, Vol. 25, No. 1, 2013, pp. 14–20), an orangy yellow sapphire filled with lead glass was presented to us by Dheeraj Gupta (Gem & Jewellery Sales Promotion Council, New Delhi).

The 4.27 ct sapphire (figure 55) was hazy throughout, with a roiled effect reminiscent of hessonite, but standard gemological properties and microscopic analysis identified the specimen as natural corundum. It gave an RI of 1.762–1.770; a hydrostatic SG of 4.03; an absorption band at around 450 nm, along with fine lines in the red end under the desk-model spectroscope; and reddish orange fluorescence in long- and short-wave UV. The sapphire showed stronger fluorescence under long-wave UV. Microscopic examination revealed numerous low-relief cracks throughout the stone with a distinct flash effect. Also visible were trapped, flattened gas bubbles, as seen in figure 56, and whitish cloudy patches; these are typically associated with filled stones. Also present were milky zones consisting of fine discs (usually rutile) and negative crystals associated with liquid films. Under diffused lighting, the glass-filled fractures appeared orangy yellow against the pale yellow bodycolor of the stone (again, see figure 56). As a result, the face-up color also appeared orangy yellow. The color of the filler glass was similar to that observed in glass-filled rubies. The lead content of the glass was further confirmed by EDXRF analysis, while the presence of iron (the cause of the sapphire’s yellow color) was confirmed by an Fe-related

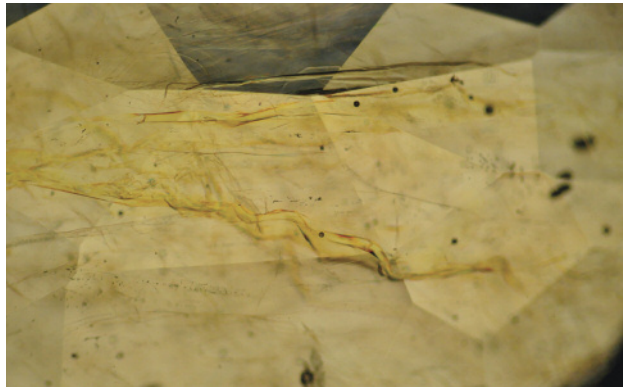


Figure 56. This 4.27 ct sapphire was filled with orangy yellow lead glass throughout the stone. Photo by Gagan Choudhary; courtesy of Dheeraj Gupta.

450 nm band in the UV-visible spectrum.

Since this was first example of lead-glass-filled yellow sapphire examined by this contributor, its market penetration is still unknown. With its transparency and color, this material qualifies as an inexpensive substitute for yellow sapphire, provided there is complete disclosure.

Gagan Choudhary (gagan@gjepcindia.com)

CONFERENCE REPORTS

Geo-Literary Society meeting. The Geo-Literary Society held its annual meeting on Feb. 14 at the Tucson Convention Center. The event, which drew attendees from the Tucson Gem and Mineral Shows, featured presentations by Scott Sucher and Al Gilbertson in a session titled “The Evolution of Diamond Cutting.”

Sucher, president of The Stonecutter in Albuquerque, New Mexico, has created replicas of famous diamonds for more than 30 years. Gilbertson, a research associate at GIA in Carlsbad, California, has authored numerous articles on diamond cut and grading, as well as the 2007 book *American Cut: The First 100 Years*.

Sucher opened the session by chronicling the early history of diamond use, global trade patterns, and advances in cutting techniques and styles. Using computer models, he compared the brilliance and fire of several early diamond cuts.

Gilbertson picked up the story with the discovery of Brazilian diamond deposits around 1725, which ushered in a period of glittery excess among European elites. David Jeffries, whose 1750 treatise described the use of a handheld “prover” to measure cutting angles, coined the term “round

brilliant” for a cut that contained 58 facets.

The discovery of massive diamond deposits in South Africa in 1867 changed the course of the industry, making these treasures available to a mass market. By 1870, there were 10,000 cutters in Europe. These artisans followed the shape of the original crystal and kept as much of the original weight as possible.

But the emphasis on weight retention was beginning to unravel thanks to Henry Morse, who set up a cutting shop in Boston around 1860. Morse, who once said, “Shopping for diamonds by the carat is like buying a racehorse by the pound,” emphasized the cut of a stone and the brilliance that resulted. He invented a gauge to measure crown and pavilion angles, and devised his own set of best proportions. He also helped develop mechanical bruting, which increased the production of round-cut diamonds.

With turn-of-the-century improvements such as the circular saw, which made it easy to cut two diamonds from a rough crystal, the stage was set for the modern round brilliant. In 1919, Belgian engineer Marcel Tolkowsky published a landmark book, titled *Diamond Design*, in which he asserted that the best-cut stones feature a 53% table, 59% total depth, and a knife-edged girdle. With some modifications to Tolkowsky’s proportions—an extended lower half, a larger table, and a closed-up culet—the round brilliant as we know it was established by 1950.

As Gilbertson pointed out, the breakthroughs in diamond cut planning and evaluation were just beginning. The Firescope viewer, developed in 1986, allowed the user to see a “Hearts and Arrows” pattern in a diamond cut to these “ideal” proportions. The Sarin scanner, introduced six years later, offered rapid, accurate proportion measurement, which led to the various cut grading services available today. Among other recent advances are inclusion-mapping software and high-speed laser cutting.

Following the presentation, Sucher invited the audience to view his faceted replicas of Cullinans I and II, the Koh-i-Noor, the Hope, and several other historical diamonds.

“Scott Sucher transported us to the early days of diamond cutting as we learned the first sources and tools,” said Dona Dirlam, the Geo-Literary Society’s secretary and the host of the session. “We saw how cutting styles evolved with improvements in the tools and an increase in the diamond supply. With each development, we saw this fascinating transformation through visual models.

“Al Gilbertson told us the largely unknown story of Henry Morse and chronicled the birth of the modern round brilliant,” Dirlam added. “As Al and Scott pointed out, today’s computer-optimized diamond cutting seems light-years removed from the earliest techniques.”

Stuart Overlin

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Most Valuable Article
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First Place

AUCTION HOUSES: A POWERFUL MARKET INFLUENCE ON MAJOR DIAMONDS AND COLORED GEMSTONES
SPRING 2013
Russell Shor

Russell Shor is senior industry analyst at GIA in Carlsbad, California. Well known in the industry for his reporting as diamond editor of *Jewelers' Circular Keystone* from 1980 to 1995, he also served as editor of *New York Diamonds* and *GemKey*. Mr. Shor holds a degree in journalism from Temple University.



Russell Shor

Second Place

RECENT ADVANCES IN UNDERSTANDING THE GEOLOGY OF DIAMONDS
WINTER 2013
Steven B. Shirey and James E. Shigley

Steven B. Shirey is a senior staff scientist at the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. Dr. Shirey, who holds a PhD from the State University of New York at Stony Brook, has published more than 125 journal articles on petrology and geochemistry, but his most recent work has focused on mineral inclusions in diamonds and continent assembly. He is a fellow of the Mineralogical Society of America (MSA), the Geological Society of America, the American Geophysical Union, and the Geochemical Society; he is also president-elect of MSA. **James E. Shigley** is distinguished research fellow at the GIA laboratory in Carlsbad, California. Dr. Shigley is editor of the *Gems & Gemology in Review* book series and contributing editor to the journal. He received his doctorate in geology from Stanford University.



Steven B. Shirey



James E. Shigley

Third Place

OPTIMIZING FACE-UP APPEARANCE IN COLORED GEMSTONE FACETING
SUMMER 2013
Al Gilbertson

Al Gilbertson is the project manager of cut research at GIA's Carlsbad, California laboratory. A former gem cutter and appraiser, Mr. Gilbertson is the author of *American Cut: The First 100 Years* (2007). He is the inventor or co-inventor on four U.S. patents pertaining to gemstone grading and analysis.



Al Gilbertson

Thank you to all the readers who voted. In addition to our winning authors, we send congratulations to **Amit Kapoor** of New Delhi, whose name was randomly drawn from the entries to win a one-year subscription to *G&G*.