GEMS & GEMOLOGY

Ruby-Sapphire Review
Nanocut Plasma-Etched Diamonds
Chrysoprase from Tanzania
Demantoid from Italy

EXPERTISE THAT SPREADS CONFIDENCE.
AROUND THE WORLD AND AROUND THE CLOCK.

ISRAEL 5:00 PM
Cutter checks parameters online with
GIA Facetware® Cut Estimator.

NEW YORK
10:00 AM
GIA Master Color Comparison Diamonds
confirm color quality of a fancy yellow.

CARLSBAD
7:00 AM
Laboratory technicians calibrate
measurement devices before
the day's production begins.

MUMBAI 7:30 PM
Staff gemologist submits new findings on
coated diamonds to GIA global database.

HONG KONG 10:00 PM
Wholesaler views grading results and requests
additional services online at My Laboratory.

JOHANNESBURG 5:00 PM
Diamond graders inscribe a diamond and
issue a GIA Diamond Dossier®

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SUBSCRIPTIONS

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ABOUT THE COVER

In the past 25 years, rubies and sapphires have gone from rare, expensive gems to material spanning all qualities and price points. The lead article in this issue, by Russell Shor and Robert Weldon, reviews the political, economic, and technological forces that have reshaped the corundum market worldwide. This sapphire necklace, designed by David Webb, has approximately 700 carats of sapphire beads. The large cabochon, with a GIA origin report stating Sri Lanka, is unheated and weighs 80.77 ct. Courtesy of Brice Jewelers, Houston, Texas; photo by Robert Weldon.

MORE ON THE "FLUORESCENCE CAGE"

We read with interest the article "'Fluorescence cage': Visual identification of HPHT-treated type I diamonds," by Inga Dobrinets and Alexander Zaitsev in the Fall 2009 issue (pp. 186–190). The authors claim that the fluorescence cage they observed is proof of high-pressure, high-temperature (HPHT) treatment of type I diamonds.

The features described are identical to those published over eight years ago by Pierre Yves Boillat and coauthors ("Luminescences sous excitation visible des diamants noirs irradiés: les luminescences d'arêtes" [Luminescence of irradiated black diamonds under visible light excitation: Facet edge luminescence], *Revue de Gemmologie afg*, No. 141–142, 2001, pp. 37–41; see also figure 1). This article has an English abstract and figure captions, as it was felt the results could interest the international gemological community. "Facet-edge luminescence" is illustrated in 17 photographs.

Hence, fluorescence cage luminescence is not characteristic of HPHT-treated diamonds. It is common among certain classes of irradiated (and sometimes annealed) diamonds. A similar phenomenon can be observed as well on natural, untreated diamonds, although there are minor differences. Ascertaining unambiguously the cause of this curious phenomenon requires further experimentation.

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REPLY: The reason we concluded that the "fluorescence cage" is related only to HPHT-treated type 1 diamonds was a simple one: We never saw this effect in diamonds except in HPHT-treated ones, and at the time of our *G&G* publication, we were unaware of the Boillat et al. article (for which we offer our apology). We did not observe the effect on irradiated diamonds that were occasionally checked together with HPHT-treated ones with the fluorescence microscope. Although one heavily electron-irradiated diamond of deep greenish blue color did show a weak "cage," this observation was not anomalous because that diamond also revealed clear features of prior HPHT treatment. We interpreted this fact as evidence of the high stability of the "cage"—that is, that it can survive heavy irradiation. Thus, from a practical point of view, we have no doubt that the "fluorescence cage" is a very strong indicator of HPHT treatment.

Concerning the occurrence of the "cage" effect in natural (untreated) diamonds, of course, it is theoretically possible. Indeed, some natural-color diamonds may reveal characteristic features of HPHT annealing or irradiation that has occurred while the gem is in the earth. In our experience, however, such diamonds are extremely rare.

Concerning the physics of the effect, we are not certain that the "fluorescence cage" seen in HPHT-treated diamonds is fully identical to the "facet-edge luminescence" observed in the irradiated stones. In some HPHT-treated diamonds we examined, the "fluorescence cage" has an appearance very different from that of the regular "cage" and that of the "facet-edge luminescence." These results will be published soon elsewhere.

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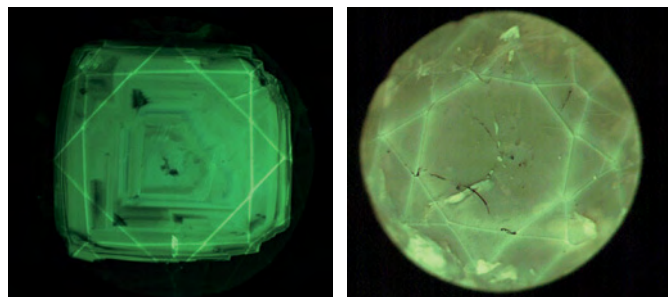
Figure 1. These photos show facet-edge luminescence in irradiated diamonds that were not HPHT treated. Left = irradiated dark green, nearly black diamond (2.5 mm); right = irradiated and heated (830°C) black diamond, magnified 30×. The same luminescence pattern was observed before heating. Photomicrographs by F. Notari.

RUBY AND SAPPHIRE PRODUCTION AND DISTRIBUTION: A QUARTER CENTURY OF CHANGE

Russell Shor and Robert Weldon

During the past 25 years, the corundum market has been transformed from one of medium- to high-priced gems to one that encompasses nearly all price ranges. This transformation was caused by the discovery of a number of large deposits and the development of treatment processes that enhanced the color and clarity of huge quantities of previously noncommercial sapphire and ruby. More recently, however, controversial treatments have undermined confidence and prices in some material, while political events and press scrutiny have affected the supply chain for rubies and sapphires from localities such as Myanmar and Madagascar.

Gem corundum—ruby and sapphire—has been among the most coveted of colored stones for millennia, historically favored by ancient Indian nobility and Asian and European aristocracy. Today, these gems continue to be sought by jewelry consumers worldwide (see, e.g., figure 1). Over the past 25 years, they have evolved from rare, generally high-priced goods to arguably the world's most widely sold colored gemstones, accounting for approximately one-third of all global colored stone sales by value (BUZ Consulting, 2009). This transformation began in the early 1980s when cutters and dealers, primarily in Thailand, began heat treating vast quantities of low-grade material from deposits in Australia, Sri Lanka, and (in the 1990s) Mong Hsu, Myanmar, to produce attractive blue and pink sapphire and ruby. As sales outlets expanded— notably to television shopping networks and the internet—the strong demand set off a surge in exploration that uncovered many new sources of rough and spurred the introduction of new treatments to transform even larger quantities of marginal material into goods attractive enough for jewelry use. While some of these treatments caused difficulties in the market that remain unresolved, prices for fine, untreated material have soared to record highs, even since the onset of a global recession in 2008.

The popularization of corundum was further sparked by the discovery of large quantities of gem rough (or treatable gem rough) at previously unknown sources in regions such as Madagascar and eastern Africa, as well as continued mining at historic localities such as Myanmar, Sri Lanka, and Thailand.

In more recent years, social and ethical issues similar to those that affected the diamond industry in the late 1990s have affected corundum as well. In

Figure 1. Fine rubies and sapphires are among the most coveted of all gems. This ruby and diamond necklace is set with 39 unheated Burmese rubies (83.73 ct total weight; the largest is 5.00 ct). Courtesy of Mona Lee Nesseth Custom and Estate Jewels and a private collector, Laguna Beach, California; photo by R. Weldon.

1999, for example, concerns over the environmental and social impacts of Madagascar's sapphire rush made international headlines. More recently, a number of countries have enacted sanctions against Myanmar, historically the world's most important source of high-quality rubies, because of that government's repressive practices.

This article reviews all of these developments, and provides results from two recent comprehensive studies of retail colored stone demand, to provide a mine-to-market analysis of corundum over the last quarter century.

GEM CORUNDUM SOURCES AND PRODUCTION

The locality of origin of a gemstone can exert a powerful influence on price and demand because of the unique attributes a specific source may impart to the material, from physical characteristics such as a distinctive color and inclusions, to the history, lore, and legend of certain gem-bearing regions. Several sources, traditional and newly found, have

supplied goods to the ruby and sapphire market over the last quarter century, as detailed below.

This section is organized into three parts: The four traditional ruby and sapphire sources, most of which have been mined since antiquity; the newer major producers that have been developed within the last 25 years; and lesser sources, several of which hold promise to be commercially important in the future.

A caveat: We have made every effort to include production figures for the individual localities where such information is available. Unfortunately, most such data are notoriously unreliable or difficult to interpret, even when coming from mine owners or official government sources. For example, quantities of rough extracted are generally reported in kilograms (1 kg = 5,000 carats) with few specifics on the quality of the material. And export data, which rarely detail various gem types, are often skewed toward the financial advantage of the exporter (i.e., often less than the actual amount if there are export taxes) and do not take into account goods illegally smuggled out of the country (a com-

Figure 2. A Kashmir sapphire's prized soft, velvety appearance, seen in this 3.08 ct gem, is caused by microscopic inclusions. Courtesy of Joeb Enterprises, Chattanooga, Tennessee; photo by R. Weldon.

mon practice in many gem-producing nations). We have, however, made every effort to find the best figures available to provide a serviceable, if imperfect, profile of ruby and sapphire production.

Traditional Sources. These sources—Kashmir, Myanmar (Burma), Sri Lanka, and Thailand—have been producing high-quality material for literally centuries. All have been active over the last 25 years, but in some cases production has seen great highs and lows, and in others political concerns have played a key role in the gems' distribution to the global market.

Kashmir Sapphire. Among gem localities, Kashmir shares the pinnacle with Mogok (for ruby) and Colombia (for emerald). Classic Kashmir sapphires exhibit a velvety, lush blue color that makes top specimens among the world's costliest—and rarest—colored gems (figure 2). Sapphires were first discovered in Kashmir (in what is now the Indian part of the region) in 1881 after a landslide revealed the blue gems high in a Himalayan mountain pass in the Paddar area west of Srinagar (Atkinson and Kothavala, 1983).

Although the Kashmir district has been at the center of a hostile border dispute between India and Pakistan for some 60 years, limited material is still being mined in the area. However, these newer goods rarely show the distinctive velvety blue of "classic" Kashmir sapphires (Michelle, 2007). J&K Minerals, an enterprise run by the Indian state of

Jammu and Kashmir to work the area around the original deposits, reported mining 15,000 kg of gem-quality sapphire between 1963 and 1998, 9 kg from 1998 to 2001, and 21 kg between 2002 and 2007—with colors ranging from near-colorless to dark blue ("Kashmir sapphire mines," 2008).

Kashmir stones continue to command some of the highest prices paid for any gem. Of the 150 top price-per-carat sapphires sold at the major auctions between 1979 and 2008, 121 were described as Kashmir (F. Curiel, pers. comm., 2008). On December 1, 2009, a private bidder paid $2.396 million for a 16.65 ct Kashmir sapphire at the Christie's Magnificent Jewels auction in Hong Kong—at almost $144,000 per carat, the most ever paid for a sapphire at auction (Christie's, 2009). In the four years prior to that sale, auction prices for top Kashmir sapphires ranged from $39,000 to $135,000 per carat (F. Curiel, pers. comm., 2009).

NEED TO KNOW

- New sources and new treatments have greatly expanded the supply of gem corundum.
- Myanmar and Sri Lanka remain major sources, and have been joined by Madagascar.
- Once a major producer, Thailand is now the world's cutting, treating, and trading center.
- Most ruby and sapphire requires treatment to be salable.
- Consumers will be increasingly concerned with social, environmental, and fair trade issues in the future.

Kashmir Ruby and Pink Sapphire. In 1979, rubies and pink sapphires were discovered on Nangimali Mountain on the Pakistani side of Kashmir (Kane, 1997, 1998). The mine, situated in extremely remote and rugged mountainous terrain, consists of two main workings (at 14,300 feet [4,360 m] and 12,500 feet [3,810 m]) that are accessible only from May to October because of the severe weather. It is one of the highest working ruby mines in the world, which helps explain why actual production did not begin until 1990.

Some of the output from this marble-hosted deposit is comparable in quality to material from Mogok. Although the rough is commonly small, one facet-grade crystal weighed 17 g (85 ct; Kane, 1997, 1998). It is believed the mine was still operat-

ing as of 2008 (R. Kane, pers. comm., 2009), but reports of more recent production are sketchy given the remoteness of the deposit and military activity in the region.

Myanmar. Burma (known as Myanmar since 1989) has been known as a source of fine ruby for more than a millennium. At the time of the first Burmese Empire in 1044, the gems were already an integral part of the kingdom's economic activity (Themelis, 2000). It has been estimated that at various periods in recent years Myanmar supplied perhaps 90% of the world's rubies (Robertson, 2007).

The term *Burmese ruby* traditionally has denoted the vivid red colors and medium-to-dark tones that were mined from the Mogok region, in Burma's Mandalay Division. These are sometimes described as "pigeon's blood red" in the trade (figure 3). Over the years, such features have given Burmese ruby a cachet similar to that of Kashmir sapphire. Since the mid-1990s, large deposits of lower-quality ruby have been found and worked at Mong Hsu, in Shan State (Peretti et al., 1995). Recently, however, all of Burma's gem riches have been the focus of negative press, with ruby and jade subject to trade bans (see Political Aspects, below).

Mogok. Many of the notable rubies mounted in royal jewels, and now seen in museums, had their origins in the mines that operate throughout the historic Mogok Stone Tract. Top-quality Mogok rubies continue to command astounding prices in the marketplace. On February 15, 2006, Christie's Geneva sold an 8.62 ct Burmese ruby (figure 4) for $3.64 million, or about $422,000 per carat. Of the more than 150 rubies that have achieved prices over $50,000 per carat at the Christie's auctions, only 12 were not Mogok stones (F. Curiel, pers. comm., 2009). Although the ruby and other gem mines and official sales were nationalized in 1969 (Themelis, 2000), in an attempt to curtail illegal mining the Myanmar government began authorizing citizens to apply for joint-venture mining leases in the ruby and sapphire districts as well as jadeite mining areas in March 1990 (see, e.g., Kane and Kammerling, 1992). Today, joint ventures between the Myanmar government and private entities still exist in Myanmar's mining areas, including Mogok and Mong Hsu, though percentages of ownership are difficult to ascertain (R. Schluessel, pers. comm., 2009). Ruby and pink sapphire are the primary products from Mogok, but significant amounts of fine blue sapphire are also recovered.

Figure 3. This "pigeon's blood red" Burmese ruby (~1 ct) and Old Mine cut diamond ring was manufactured circa 1910. After the 1885 annexation of Upper Burma by the British, rubies began to enter the European gem markets in earnest. Courtesy of Frank Goodman & Son, Los Angeles; photo by R. Weldon.

Figure 4. The Graff Ruby, an 8.62 ct Burmese stone set into a ring by Bulgari, sold for a record $3.64 million—about $422,000 per carat—at the Christie's February 2006 auction in St. Moritz. Photo by Denis Hayoun/Diode SA; courtesy of Christie's International.
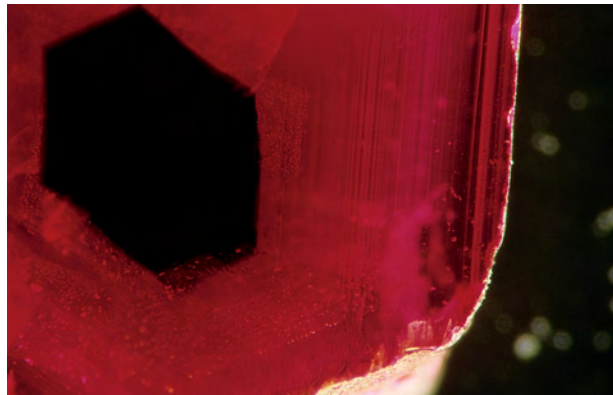
Figure 5. Mong Hsu crystals typically have a red rim surrounding a violet to dark blue core. Heat treatment causes the blue coloration to disappear, resulting in a uniformly red (ruby) crystal. Photomicrograph by Edward Gübelin.

Figure 6. This 6.21 ct ruby from Mong Hsu is heat treated, as are most stones from this locality. Courtesy of Pillar & Stone International, Tiburon, California; photo by R. Weldon.

Mong Hsu. In late 1992, rumors of a new discovery of corundum in Myanmar began circulating in the trade, and vast quantities of gems appeared in Bangkok, though the color tended to be much lower in quality than that of traditional Mogok material (Peretti et al., 1995). Mong Hsu quickly became the world's largest supplier of corundum during the early and mid-1990s. Articles reporting on and describing the new material—vastly different from that of Mogok—began circulating in trade journals and scholarly publications (e.g., Kane and Kammerling, 1992; Peretti et al., 1995; Schmetzer and Peretti, 1998; Drucker, 1999b). In fact, the gems from Mong Hsu were so different from the Mogok material that the phrase *Burmese ruby* acquired a qualifier in the trade: *Mogok* or *Mong Hsu*.

Mong Hsu's corundum was often difficult to characterize because the crystals had unique color zoning: transparent red outer rims with cores that typically appeared violet to dark blue (e.g., figure 5). Heat treatment improved the salability of this material by converting the violet and dark blue cores to yield uniformly red stones (e.g., figure 6). It also produced characteristic features, such as inclusions of white particles easily seen with magnification. Note, too, that Mong Hsu rubies typically contain cavities and fissures that may be filled with glass during the heating process (Hughes and Galibert, 1998). A similar process (with borax as a flux) had been widely used decades earlier during the heat treatment of Burmese and Thai rubies (Kane, 1984).

Since 2004, production from Mong Hsu has dwindled considerably (R. Schluessel, pers. comm., 2009). The primary reason is that easily accessible areas of the deposit have been exhausted, but the government reportedly has also relocated large numbers of workers to other mining projects such as for gold and uranium (Helmer, 2008).

Nanyaseik (Namya). In 2001, a rumor circulated among gem dealers regarding a gem rush in an area near Hpakant in Shan State (Peretti and Kanpraphai, 2003). It soon became a short-lived new source of extremely fine-quality rubies—as well as sapphires and spinels—not unlike those from legendary Mogok. Experts say most of the material was quite small, but with rich, "true" colors not affected by gray or brown secondary hues (W. Larson, pers. comm., 2009). Stones in the 2–5 ct range were uncommon, and fine 10+ ct gems were very rare (Peretti and Kanpraphai, 2003). The area was exploited heavily between 2001 and 2004, but production has slowed to a trickle since then (Hlaing and Win, 2008).

Political Aspects. In recent years, *Burmese ruby* has acquired some negative socio-political connotations, particularly in the United States and Europe. The source of this is the well-documented human rights abuses—of ethnic minorities and common citizens alike—committed by Myanmar's ruling generals (see, e.g., U.S. Department of State, 2009). Further, many of these abuses have been linked to the gem trade (Jewelers of America press release, 2007; Newell and Gadner, 2007). It has been widely reported by the same sources and numerous mass media (see, e.g., Associated Press, 2007; Walt, 2007) that the

military junta—the State Peace and Democracy Council—owns a controlling interest in the mining and sale of gems that are exported officially.

In 2003, the U.S. Congress responded by enacting the Burmese Freedom and Democracy Act, ostensibly to ban trade with Myanmar. However, the law had a loophole that permitted Burmese gemstones to be legally imported into the U.S. if they were cut (i.e., markedly transformed) in and exported from another country. Since so much Burmese material is processed in other countries, particularly Thailand, this had the effect of exempting many Burmese gems from the ban. The European Union also passed a series of economic sanctions, including an embargo on the importation of gems from Myanmar (Human Rights Watch, 2008). A few years later, the U.S. Congress closed the loophole in the 2003 legislation with passage of the Tom Lantos Block Burmese JADE Act of 2008, which specifies that any ruby and jadeite *mined* in Myanmar cannot be imported into the U.S. for commercial purposes. Other gems, such as sapphire, are not included, though importation of rough sapphires is still prohibited by the 2003 act.

The intent of the JADE Act and the EU legislation was to deny the junta revenues from gem sales (though the junta's primary source of funds is natural gas). The sanctions were also aimed at encouraging the government to free pro-democracy activist Aung San Suu Kyi, the 1991 Nobel Peace Prize winner, who has been held under house arrest (or in Myanmar's notorious Insein prison) for 14 of the last 20 years (Tran, 2009). Nevertheless the sanctions have generated some controversy in the gem trade. On the one hand, U.S. retail jeweler Tiffany & Co. ceased buying and selling Burmese gemstones after the passage of the 2003 Act (Tiffany & Co., 2009), and Jewelers of America worked to make its members aware of the political ramifications of continuing to buy gems from Myanmar. On the other hand, some gem dealers have argued that the sanctions would actually harm Myanmar's artisanal gem miners ("ICA criticizes Burma ban," 2008; Rosenbusch, 2008).

The sanctions have resulted in the closing of nearly 50 ruby mining sites, while official sales of all gems fell from 7.2 million carats in 2007 to 6.5 million carats in 2008 (Kyaw-Zaw, 2009). Nevertheless, official Myanmar figures tallied nearly $647 million in gem exports in the fiscal year 2007–2008 (Moe, 2009); the majority of those revenues were

Figure 7. Sri Lanka is the source of many colors of sapphire. This multicolored suite (1.47–7.34 ct) was cut by Mark Gronlund using concave faceting techniques. While concave faceting has traditionally been used with inexpensive gem materials, innovative cutters increasingly use it with corundum. Courtesy of Mark Gronlund, Umatilla, Florida; photo by R. Weldon.

from jadeite, not rubies and sapphires. Reports also stated that buying by foreign dealers fell 50% after the introduction of the U.S. trade ban (Moe, 2009). Note, though, that it is impossible to obtain true production numbers because a large percentage of the corundum mined in Myanmar is smuggled into Thailand (Elmore, 2005).

Sri Lanka. It is believed that the very first sapphires known to Europeans came from Ceylon (now Sri Lanka) after Alexander the Great invaded the Indian subcontinent in 325 BC. A flourishing commerce in sapphires and rubies from that island nation took root later, during the Roman Empire, when active trading along the famous silk route existed between Rome and India (Hyrsl, 2001).

Today, many colors of sapphire (e.g., figure 7) and occasional rubies continue to be found in riverbeds and other alluvial deposits in Sri Lanka , and the island nation is still a preeminent source for star sapphires and rubies (Robertson, 2002; figure 8). Although the government has recently granted

Figure 8. Sri Lanka is known for producing corundum's phenomenal varieties, including asteriated gems. This collection of star sapphires (and one ruby) ranges from 2.65 to 15 ct. Courtesy of Rafco International, New York; photo by R. Weldon.

some licenses for mechanized mining in a section of the Kalu Ganga riverbed, near Ratnapura, much of the country's production still comes from small-scale rudimentary operations (Berenger, 2009).

Even though Sri Lanka, like Myanmar, continues to be a major producer of high-quality sapphires and rubies, this fact is often obscured by the extensive production of low-value whitish corundum (*geuda* sapphire). This material first became meaningful in the 1970s when Thai dealers discovered that it could be heat-treated at high temperatures (1500°C and above) to achieve greater transparency and pleasing blue colors (Nassau, 1981). Vast quantities of geuda were purchased and exported to Thailand for treatment. The importance of this development in the corundum marketplace cannot be overstated, both because heat treatment remains a critical factor in the corundum market today and because it functioned as a precursor to other types of heat-related treatments. The 1980s marked the point at which the treatment of previously worthless material suddenly resulted in the widespread availability of appealing blue sapphires.

Sri Lanka has sought in recent years to regain its stature as the source of high-quality sapphires of many colors, including the rare pinkish orange

"padparadscha" (figure 9), and ruby, as well as star ruby and sapphire (Hughes, 2003). The country's National Gem & Jewellery Authority, noting that sapphire accounts for about 50% of total earnings from gem exports, announced initiatives in 2008 described as "differentiating and positioning Ceylon sapphires at the top end of the sapphire spectrum in all categories" (Prematilleke, 2008b, pp. 63–64). These initiatives focused on creating a brand for the country's small percentage of untreated sapphires above 3 carats, in order to attract more global buyers.

Unfortunately, supplies of Sri Lankan sapphires in general—but untreated in particular—had diminished in the years immediately preceding the initiatives, resulting in dramatic price increases. Production of blue sapphires, the principal object of Sri Lanka's branding efforts, declined 66.9% between 2006 and 2007, from 472,961 carats to 156,486 carats, while the price per carat rose 18.9%, according to the report, and per-carat prices for untreated goods soared (Prematilleke, 2008a). Additionally, the supply issues in Sri Lanka coincided with decreased availability of material from Madagascar after the spring of 2008—leading to a general scarcity of sapphire supplies worldwide.

Figure 9. Sri Lanka is also an important source of pinkish orange "padparadscha" sapphires, like this untreated 88.11 ct gem. Courtesy of Evan Caplan, Los Angeles; photo by R. Weldon.

Figure 10. Small sapphire mining operations, such as this one in Chanthaburi, are still active in some parts of Thailand. Photo taken in July 2008 by R. Shor.

Thailand. *Mining and Production.* Accounts of rubies from the Kingdom of Siam, as Thailand was called until 1949, date back to the 15th century, and figure importantly in reports from European travelers and traders who visited the area between 1600 and 1800 (Hughes, 1997). Historically, most of these early accounts referred to the area that straddles the border between present-day Thailand and Cambodia.

Although the sensational quality of Kashmir sapphire would overshadow the traditional Siamese goods, the kingdom was still regarded as the most important source of blue sapphire, by quantity, until 1907 when it was forced to cede its eastern provinces, including Pailin (now in Cambodia), to the French colonial regime in what was then Indochina. In the 20th century, other areas of Siam were opened to corundum mining, and by the mid-1930s, Siam was reportedly producing half the world's sapphires (Gravender, 1934).

Mining apparently halted in the region during World War II and its aftermath. It eventually resumed on a small scale until 1978, when a large deposit was discovered that yielded dark blue colors after heat treatment. Not quite as dark as Australian goods (see below), most Thai sapphires found their way to the better end of the commercial market (Hughes, 1997). The deposit, located close to Bo Phloi in western Thailand, attracted several large, mechanized mining operations. Nine years later, in

1987, geologists reported that the Bo Phloi deposit was much more extensive than previously believed, and the opening of several more major mines made the region one of the world's largest sources of blue sapphire. Production began to decline in the mid-1990s, with less than 200 kg recovered annually from 1995 through 2005, a tiny fraction of the world total (Yager et al., 2008). In recent years, only one large Thai-based concern, SAP Mining Co., has continued to operate in the Bo Phloi area, along with scattered smaller operations elsewhere in the country (e.g., figure 10).

Thailand's ruby production, mainly in Trat Province, was sporadic through the early years of the 20th century. In the 1960s, production rose steadily to make Thailand a leading source until the Mong Hsu discovery. Like much of its blue sapphire, Thai ruby tended to be darker than what most dealers consider optimum, though heat treatment could often lighten the color by removing purple or brown secondary hues (Nassau, 1981; Keller, 1982). Production from the three mining areas in Trat peaked in the 1980s, as mechanized operations took over. By the 1990s, most of the known deposits had played out, with production estimated at 15–30 kg yearly through 2005 (Hughes, 1997; ICA 2006 World Gemstone Mining Report, 2006; Yager et al., 2008).

Thailand as a Gem Cutting and Trading Hub. Even as the country declined as a gem producer, mem-

Figure 11. While there are still crowds of dealers and buyers at the open gem market in Chanthaburi, political and economic events as well as supply problems have diminished both the quantity and quality of goods offered. Photo taken in July 2008 by R. Shor.

bers of the Thai industry moved aggressively to retain and expand their role as the world's primary dealers and distributors of corundum. They did this by buying the majority of corundum production from other sources, such as Sri Lanka, Australia, Tanzania, and Madagascar, and by developing treatment methods that allowed them to process much greater quantities and quality ranges of material.

Today, an estimated one million Thais make their living from the gemstone industry through cutting, trading, and treating ("Thailand government waives VAT. . . ," 2009). Approximately 70% of the world's sapphires and 90% of its rubies pass though Thailand. Most are treated and cut in Chanthaburi, where the weekend gem markets still draw thousands of buyers and sellers (figure 11), and are then exported through Bangkok (ICA 2006 World Gemstone Mining Report, 2006).

Figures published by the Gem and Jewelry Institute of Thailand (2009) indicate that polished gemstone exports in 2008 totaled approximately $254.89 million, of which sapphire represented 46.7% and ruby 40.62%. Although the export value of cut gemstones increased nearly 50% between 2007 and 2008, imports of rough declined 13% ($22.9 million to $19 million) for the same period.

Recent advances in treatment, such as beryllium diffusion (see the Effects of Treatments section below), caused a severe crisis in confidence, sending demand and prices for some colors (mainly yellow to orange) of commercial-quality treated sapphire to historic lows (Shor, 2008). Additional challenges have been created by a 2008–09 embargo on exports from Madagascar, the U.S. and EU bans on ruby from Myanmar, the global economic downturn, and political instability in Thailand (Shor, 2008).

Even before these issues arose, the Thai trade began to see problems. Early in 2007, the country's two major trade associations, reacting to the closure of many cutting operations, petitioned the government for assistance (Shor, 2007b). After gemstone exports plunged by one third, from $130.5 million during the first half of 2008 to $88.2 million for the corresponding period of 2009 (Gem and Jewelry Institute of Thailand, 2009a,b), the Thai Ministry of Commerce waived the value-added tax on rough and cut gemstones from countries that did not have a trade agreement with the government and crafted a loan package totaling $148 million to assist small- and medium-sized businesses ("Thailand to become. . . ," 2009). At this writing, the program has not been in effect long enough to determine its impact.

Newer Major Sources. These sources—Australia, Madagascar, and Vietnam—had a major impact on world corundum production over the last quarter century. While only Madagascar continues to be a major source of sapphire and, to a lesser extent, ruby, all played a significant role during this period.

Australia. Australia's prolific sapphire production from the late 1970s through the 1980s helped, along with Sri Lanka, to usher in the era of mass-market corundum, with vast quantities of lower-priced, inky blue material that became a staple in popular calibrated-cut-stone jewelry (Hughes, 1997).

Actually, the country was one of the world's premier sapphire sources early in the 19th century (Coldham, 1985). The Anakie deposit in central Queensland proved to be the largest, with some 2 tonnes of corundum mined there by 1913. However, production waned after World War I, as the prime-color material was mined out and the vast majority of what remained was clouded with silky inclusions and deemed too dark for commercial use. During the 1960s, however, the Thais refined heat treatment effectively enough to remove these silky inclusions

Figure 12. Madagascar has been an important source of sapphires since 1993–94. Many have come from hand-dug pits such as this one at Ilakaka. Photo taken in July 2003 by Brendan M. Laurs.

and thus somewhat lighten the stones, making the Australian material more commercially viable (Coldham, 1985; Hughes, 1997).

Thai traders established buying operations in Australia in the late 1960s, spurring expanded production. In addition to restarting the Anakie fields, miners began working Invernell, a known sapphire source in New South Wales that was subsequently discovered to be part of a much larger deposit later called the New England gem fields. A third area, Lava Plains, in Queensland, produced significant quantities of sapphire for several years from the late 1980s until 1993. The introduction of modern, mechanized sapphire mining meant that large quantities of material entered the market in a short period (Hughes, 1997). During the 1970s and through the early 1990s, Australia produced an estimated 70% of the world's sapphire. The best qualities were often separated out and marketed as "Thai," "Sri Lankan," or "Cambodian" (Beard, 1998).

Production from Australia peaked in the mid-1980s but remained high through the next decade as smaller deposits, particularly in the New England area, in addition to Lava Plains, were discovered and worked to exhaustion after a few years ("Australian sapphires," 2005). However, rising mining costs and tough environmental restrictions, coupled with the continued low prices, discouraged further exploration to replace areas that had been played out (Beard, 1998).

From 1995 to 2005, Australia's sapphire production declined by some 60%, from an estimated 13,000 to 5,500 kg (Yager et al., 2008). However, a number of areas remain open to "fossicking" (hand digging), and in late 2007 the Queensland government indicated that some mechanized production might restart at Lava Plains (Neville, 2007).

Ruby was mined along the Gummi River north of Sydney between 2004 and 2006, with the mine operator, Cluff Resources, reporting that 440,000 carats of cabochon- and some facet-grade material were extracted. The company suspended operations early in 2007 after local governments declined to approve a request to extend mining operations to a broader area (Cluff Resources, 2007).

Madagascar. *Sapphire.* Madagascar has developed into the most important source of sapphire, blue and fancy colored, within the past two decades (see, e.g., figure 12). Corundum finds there were minor until 1993–94, when attractive blue sapphires were found in the Andranondambo area of the island's southeast corner. The deposit proved lucrative, with some 1,200 kg exported to Thailand annually for the next three years and a number of 15–20 ct stones cut. A very high percentage of this material responded well to heat treatment, and some of the best-quality goods were compared to Kashmir sapphire (Schwarz et al., 1996).

The first truly major find came in 1996, in the Antsiranana region at the extreme north of the country. Within two years, the area became one of

the world's most productive sources of commercial-quality sapphire, as an estimated 10,000 miners worked small claims with hand tools while traders from Thailand and Nigeria bought and exported the production (Schwarz et al., 2000). However, in 1998 the government temporarily halted activities in the area after miners encroached on the nearby Ankarana nature preserve ("Sapphire mining halted," 1998). The ban was lifted within a few months, but by then discovery of an even-larger sapphire deposit had enticed the miners and dealers to travel more than 1,200 km south to the small village of Ilakaka.

What made the Ilakaka find so notable was its immense size—huge amounts of sapphire (some 4,500 kg; Yager et al., 2008) entered the market very quickly in 1999—as well as the attractive blue color of some of the material and the fact that it generated international headlines. The hundreds of pits dug in the area (again, see figure 12) also yielded other colors (Johnson et al., 1999; figure 13). Although much of the production was small (less than 1 ct) and of commercial quality, some of the material rivaled the best Sri Lankan sapphires. Pink sapphires from that area supported the market through a wave of popularity in the mid-2000s (Pardieu and Wise, 2005). The Ilakaka discoveries came at a fortuitous time. As noted above, the traditional sap-

Figure 13. The sapphire production from Madagascar (here, 0.45–1.99 ct, primarily from Ilakaka) is notable for the broad range of colors produced. Courtesy of Robert Kane/Fine Gems International, Helena, Montana; photo by R. Weldon.

phire sources in Thailand were nearing depletion and the large Australian deposits were winding down, so most of the stones reaching the market came from Sri Lanka and relatively small workings in Myanmar and Tunduru, Tanzania. Ilakaka is still producing material, but mining activity was severely curtailed during a 2008–09 export embargo and by the fact that the easily worked areas were depleted (T. Cushman, pers. comm., 2009).

Because a high percentage of the sapphires produced were smuggled out of Madagascar, production statistics tend to be incomplete and contradictory. One report said that by 2005, Madagascar was responsible for an estimated 50% of the world's sapphires (Tilghman et al., 2007). However, a U.S. Geological Survey (USGS) study placed Madagascar's sapphire output at 25–40% of world share between 2000 and 2005 (Yager et al., 2008). Note, though, that the USGS study was based on voluntary responses to questionnaires and did not include material smuggled from any source country including Madagascar. In addition, the USGS reported that Madagascar's sapphire production climbed from 140 kg in 1995 to over 9,500 kg in 2000, receding to 4,700 kg in 2005 (Yager et al., 2008). But the stated value of legally exported material was far lower than such large quantities would indicate. Tilghman et al. (2007) reported that the overall value of "precious stones" (the vast majority of which were sapphires) produced in and legally exported from Madagascar was only $7.63 million in 2005, up from $5.84 million in 2001 and $2.61 million in 1998. This may be explained by a claim that 50 kg of sapphire were smuggled to Thailand each week, supported by a World Bank estimate that the country saw less than 5% of its potential revenues from sapphire exports ("Getting stoned," 2005).

Ruby. Madagascar also has been an important source of rubies. One major find, in September 2000, was in Vatomandry near the eastern coast. The material was high quality and generally pinkish red to red (e.g., figure 14), with the finer goods comparable to Mogok rubies. About 30–40% was marketable without heat treatment (Leuenberger, 2001). Fearing a repeat of Ilakaka's uncontrollable gem rush, government authorities quickly sealed the area to miners and divided it into concessions, though by 2005 most miners had left the area because all the easily worked deposits were played out (Hughes et al., 2006).

Figure 14. In their best qualities, rubies from Madagascar's Andilamena deposit (above, cut stones 4.85 and 5.02 ct) have bright refractive qualities and slightly orangy red hues. Vatomandry rubies (below, cut stones 1.78 and 2.03 ct) show desirable pinkish red to red colors. Courtesy of Allerton Cushman & Co., Sun Valley, Idaho; photo by R. Weldon.

About the same time, a second deposit was discovered in north-central Madagascar, near the town of Andilamena in a difficult-to-access rainforest. Again, a boomtown appeared nearly overnight, with an estimated 40,000 miners descending on a previously uninhabited locality. The government tried to seal the area, but was stymied by the challenging logistics. Although the material was quite plentiful and the best stones were a bright, slightly orangy red (again, see figure 14), the commercial stones tended to be over-dark and most of the rough was fractured and—at the time—unmarketable as gems (Leuenberger, 2001). That would soon change.

In 2004, large quantities of lead glass–filled ruby began filtering into the market, much of it from the Andilamena deposit. This treatment was different from the borax-based glasses and flux residues mentioned above. The infusion of lead glass disguised the fractures and transformed pale, opaque material into attractively colored, translucent rubies. The stones were competitively priced, between $2 and $20 per carat, and proved easily identifiable (McClure et al., 2006). As the Andilamena deposit was mined out, however, the quality of the material deteriorated even further, with the result that many "rubies" reaching the market consisted more of

lead-glass filler than actual corundum ("Gem treatments. . .," 2009; see also the Effect of Treatments section below).

Environmental and Social Challenges. The government's concern about Madagascar's gem rushes was justified, as the boomtowns attracted more than miners, gem dealers, and news media. Stories of violence, corruption, disease, and environmental damage rapidly became an integral part of the international reporting on the Ilakaka sapphire rush (see, e.g., Hogg, 2007).

In addition to the problems documented at Ilakaka, reports have also cited the extensive damage to the country's rainforests and nature preserves by miners digging for gems, often abetted by corrupt officials who sometimes have a vested interest in mining activities ("Getting Stoned," 2005; Tilghman et al., 2007). Environmentalists are particularly concerned because an estimated 80–90% of Madagascar's indigenous plant and animal species exist nowhere else (Tilghman et al., 2007).

And, as noted above, the gem rushes have failed to bring commensurate benefits to Madagascar's treasury because of smuggling.

In 2003, the country's newly elected president, Marc Ravalomanana, moved to reform national gem mining policies in hopes of reducing illicit exports and gaining more revenues. He also sought to limit environmental damage by controlling gem rushes and enforcing bans on gem mining in national parks. The policy reforms simplified the complex system for licensing gem mines, established gemological training programs, and permitted foreign companies to mine and export gems. While winning praise from the World Bank and other development agencies (Duffy, 2005), the reforms stalled early in 2008 after the Secretary General of Mines banned all gem exports (Shor, 2008). In July of that year, a delegation from Thailand, including several government officials and members of key Thai gem trade associations, met with Malagasy officials to have the ban lifted. They succeeded in eliminating the ban on cut stones, but not that on rough, which remained in effect until mid-2009, though an unknown quantity of goods still exited the country illegally. So many dealers and miners reportedly left Ilakaka that the town shrank to one-fourth its peak size (T. Cushman, pers. comm., 2008).

In March 2009, Mr. Ravalomanana was forced from office in a coup, and on July 17, the ban on gemstone exports was completely lifted by the min-

ister of mines for the interim government, Jean Rodolphe Ramanantsoa. He noted that the 19-month ban ultimately cost the government $39 million in revenue and affected the livelihoods of more than 100,000 Malagasy artisanal miners (Cushman, 2009).

Vietnam. In the late 1980s, rumors of a major ruby find in Vietnam began circulating through the world's gem centers. To help manage the newly discovered deposits, the Vietnamese government created the state-owned Vietnam National Gem and Gold Corp. (Vinagemco) in 1988 to engage in prospecting, mining, processing, and trading of gem materials. From November 1989 to March 1990, an estimated three million carats of ruby were mined from the Luc Yen district, north of Hanoi. Described as "Burmese color," the ruby began hitting the Bangkok gem markets in 1990 and 1991 (Kane et al., 1991).

In 1991, the Vietnamese government established a joint venture with a Thai operation, B. H. Mining Co., to begin mechanized extraction in the Luc Yen area. By 1994, mechanized operations had ceased because the deposits were no longer economic (Kammerling et al., 1994). In general, the Luc Yen ruby, and its small quantity of blue and pink sapphire, was of good color but relatively low clarity—only a small percentage was eye clean.

Several hundred kilometers to the south, at the top of the Ho Chi Minh trail, discovery of rubies in the Quy Chau area attracted thousands of local diggers in the early 1990s before the government moved in to organize operations. A third major find occurred in 1994 at Tan Huong, about 80 km south of Luc Yen. From 1994 to 1996, hundreds of kilograms of rubies and star rubies were mined illegally and sold to foreign dealers until the deposit was taken over by Vinagemco. As at Luc Yen, the rubies were red to purplish red. Sapphires—orange, blue, and violet—were also found in these two areas, though in much smaller quantities than ruby. Several relatively small deposits of blue sapphire were located during the 1990s in the southern and central portions of the country (Van Long et al., 2004).

Most of Vietnam's corundum deposits, while yielding large quantities of material in a fairly short time, were no longer commercial after a few years (Van Long et al., 2004). For example, Vietnam's sapphire production soared from an estimated 40 kg in 1996 to 1,700 kg two years later, but by

2001 production was down to 70 kg (Yager et al., 2008).

By 2006, these areas were mainly worked by local diggers who extracted relatively small quantities of material, illegally in some cases, and sold them to Thai dealers (ICA 2006 World Gemstone Mining Report, 2006). Most reports note the promise of more deposits awaiting discovery, but to the best of our knowledge the government has yet to undertake a detailed geologic survey.

Lesser Producers. A number of other countries produce ruby and sapphire from generally small- to medium-sized deposits. Several, however, may have the potential to develop into significant producers.

Cambodia and Laos. In Cambodia, most sapphire production over the years has come from Pailin, near the border with Thailand. Pailin was known for yielding commercial quantities of blue sapphire as well as much smaller amounts of purplish to orangy red ruby (ICA 2006 World Gemstone Mining Report, 2006). During the 1950s through the 1970s, the nation was sealed to the outside world as the war in Vietnam raged, until late 1978 when the Khmer Rouge were driven from power by the Vietnamese army.

Subsequently, some former senior Khmer Rouge army officers took control of the local sapphire deposits, selling mainly to Thai dealers. Although the amount produced was no longer significant (Yager et al., 2008), Pailin's association with the architects of the Khmer Rouge regime attracted unfavorable international publicity for sapphires at a time when the diamond and tanzanite industries were similarly under fire. In 2002, enough sapphires were coming out of the ground that a British Broadcasting Corporation (BBC) report described Pailin as a "Wild West" type gem market, with "hundreds of thousands of dollars" worth of goods on display (Pike, 2002). The gems shown in the BBC report were nearly the last to come from the area because, by 2006, it had essentially ceased production (ICA 2006 World Gemstone Mining Report, 2006).

In Laos, sapphires have been mined at Ban Houay Xai, an area adjacent to the intersection of the Thai-Burmese border, since the 1890s. Not until 1995, however, was an attempt made to systematically mine the deposit. An Australian company, Gem Mining Lao, operated the mine for several years, producing primarily dark blue material,

before the local government seized its assets in December 2000 in a dispute over concession areas and royalties (Radio Free Asia,, 2000). By 2005, the area was worked by only a handful of small-scale miners (Pardieu and Senoble, 2005).

China. A farmer reportedly found the first Chinese sapphires on Hainan Island in the early 1960s (Galibert and Hughes, 1995). However, China's sapphire deposits are mostly located in the eastern side of the mainland. Much of its production is characterized by dark-toned blue colors, though greens, blue-greens, and yellowish greens are also found. The basalt-hosted material found at Mingxi in Fujian Province (Keller and Keller, 1986; Guo, 1992) and Changle in Shandong Province is comparable to the dark-toned sapphires from Australia. Supplies are sporadic because of informal mining techniques (Weldon, 2009). Nevertheless, the Chinese government apparently believes in their potential, as it has committed enormous resources to developing infrastructure, such as the Gem City Complex in Changle, to support sapphire mining and processing in the future. Thus far, the sapphires have been intended for local consumption and for the tourist trade; however, the Gem City Complex will accommodate thousands of miners, cutters, jewelry factories, and retail outlets. Officials have noted that other gems will also be processed at these facilities (Weldon, 2009).

Greenland. The world's largest island, Greenland, has a potentially interesting ruby source under development. True North Gems, a publicly traded Canadian company, began exploring a large area (823 km^2) on the southwest coast in 2004, producing pink sapphires and rubies, mostly less than 1 ct. True North reported recovering 1,297 kg of near-gem ruby and pink sapphire, and about 65 kg of gem-quality material (Weston, 2009). A limited amount of this material has been set into fine jewelry (e.g., figure 15).

The project is currently in a dispute with the Inuit people over their ability to prospect in areas controlled by True North, which the Inuit consider their right under Greenlandic mineral law. True North is also prospecting the Beluga sapphire project on Baffin Island (Carpin, 2009; Weston, 2009).

Kenya. The John Saul mine, located in the Mangare area not far from the tsavorite deposits, has been Kenya's most important and productive ruby mine

Figure 15. This pendant (named La Jenna) and matching earrings are set with Greenland rubies and pink sapphires (37.45 carats total weight). Courtesy of True North Gems, Vancouver, BC, Canada; photo by R. Weldon.

(ICA 2006 World Gemstone Mining Report, 2006). Operated by Rockland Kenya Ltd., it is also Africa's largest mechanized ruby operation, producing mostly cabochon-grade material that is heated to produce saturated red colors. About 200–500 kg of mixed-grade material (figure 16) is recovered monthly, with only a small percentage achieving top-grade cabochon quality (Laurs, 2008). Other deposits of jewelry-grade ruby have been found in Kenya, notably the Baringo deposit north of Nairobi, discovered in 2005, and the Simba deposit found in 2007. Both are promising, with their finest qualities of pinkish red rubies exhibiting great transparency. However, investment funding, logistical problems, and—in the case of Baringo—disputes over mine licenses, have limited the output from both mines to very small quantities (N. Pattni, pers. comm., 2009).

Malawi. Corundum was discovered at Chimwadzulu Hill, in southern Malawi, in 1958 (Rutland,

Figure 16. Pavel Sobolev (left), a buyer from Russia, examines an assortment of rough ruby at the John Saul mine in Kenya, one of Africa's most productive deposits, while the company's sorters process the goods. Photo taken in May 2007 by R. Weldon.

1969). Today, the production tends toward pink, red (e.g., figure 17), and purple (much of which does not require heat treatment), in sizes yielding a maximum of 2–3 ct gemstones (Rankin, 2002). Some 4–5 kg of material have been mined annually in recent years (ICA 2006 World Gemstone Mining Report, 2006). More recently, approximately 50–100 kg of yellow and blue sapphires have been produced, though the blue sapphires are routinely heated (E. Braunwart, pers. comm., 2009).

Tanzania. Ruby and sapphire deposits in East Africa have been known since the early 1900s (see, e.g., Dirlam et al., 1992). In late 1994, a variety of allu-

Figure 17. Ruby (here, 1.51 ct) and pink sapphire (0.73 ct) were first found in Malawi half a century ago. Today they are being mined in accordance with fair trade principles that use company-devised protocols at all levels of the gems' supply chain. Courtesy of Columbia Gem House; photo by R. Weldon.
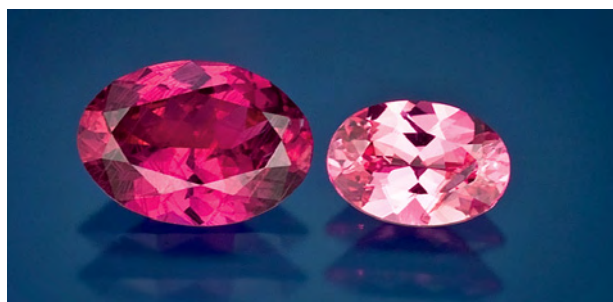
vial gem rough began appearing in Tanzanian gem markets in Mombasa and Arusha (Weldon, 1995). Farmers had discovered these gems in riverbeds near Tunduru, and the area was soon hailed as one of East Africa's major gem finds. The corundum included pink-to-red, dark red, yellow, blue, violet, green, and color-change varieties. (The deposits also yielded other gems such as beryl, chrysoberyl, diamond, garnet, quartz, tourmaline, and zircon.) The gems were derived from the massive geologic province and gem-bearing complex known as the Mozambique Belt (Johnson and Koivula, 1996; Henn and Milisenda, 1997).

Additional deposits were soon found about 140 km west of Tunduru in the region of Songea. Interestingly, gems from the two areas shared similar characteristics, although Songea produced significantly more rubies (Johnson et al., 1999b). Material from Songea acquired a different notoriety in 2001, when quantities of pinkish orange to red-orange sapphires, said to come from this locality, began to enter the market. Dealers had not previously seen such material at the source, so a new treatment was suspected (Hughes, 2001). The suspicions were correct, as the stones had been diffusion treated with beryllium to create padparadscha and other colors (Emmett et al., 2003). Ultimately, thousands of the treated stones were sold without disclosure (see Effect of Treatments, below).

In 2007, ruby and sapphire from Winza, in central Tanzania, began to enter the market. These gems were mined from primary as well as secondary deposits (figure 18). This happened at a time when supplies of corundum and other rough were low because of the situations with Madagascar and Myanmar. The extraordinary transparency and bright color of the best Winza rubies have prompted comparisons to top Burmese material, with some stones as large as 20.46 ct (Schwarz et al., 2008; Wise, 2008a; figure 19). Winza's gem corundum ranges from blue to red, sometimes with both colors exhibited in the same crystal. A significant percentage of Winza gems are not heat treated, which has contributed to their desirability. Winza also produces ample quantities of lower-grade ruby and sapphire suitable for cabochons (Peretti et al., 2008; Schwarz et al., 2008). Attempts to heat treat this material have not resulted in significant improvement.

Pakistan, Afghanistan, and Elsewhere in Central Asia. Rubies from both Pakistan and Afghanistan

Figure 18. Rubies and sapphires from the Winza deposit in central Tanzania are recovered from primary deposits as well as from eluvium, which is wet-sieved using water from the adjacent seasonal river. The miners employ portable gasoline-powered pumps to make pools of water during times of low rainfall, as in this June 2008 photo. Photo by Brendan M. Laurs.

are hosted by marble and generally found in small sizes (Gübelin, 1982). The best stones can resemble gems from Myanmar, Vietnam, and Sri Lanka (Hughes, 1997). There are several challenges to mining these deposits, beyond those inherent in this war-torn region: tribal rivalries, rugged terrain, and an almost nonexistent infrastructure (Snee, 2006). Bringing steady supplies to market under such conditions is daunting at best.

In Pakistan, rubies have been mined from marbles on Nangimali Mountain (see Kashmir section above) and from a few deposits in the Hunza Valley near Ahmadabad (e.g., Laurs, 2007). Production from the Hunza Valley has remained small throughout its history, though reserves appear large; investment in heavy machinery and infrastructure is needed to develop these hard-rock deposits ("Pakistan's gemstones. . . ," 2005). Small deposits of rubies and predominantly purple sapphires have been found in the Basha Valley (northern Pakistan; Laurs, 2007) and Batakundi (North West Frontier Province; Quinn and Laurs, 2004).

In neighboring Afghanistan, marble-hosted rubies and sapphires occur mainly at Jegdalek, some 60 km southeast of Kabul. According to a 2009 status report on the Afghan gem industry (Bowersox et al., 2009), a government-imposed moratorium on gem mining has resulted in scant production in recent years. Flooding at Jegdalek has also halted activity at some of the sites. Nevertheless, some two dozen mines are on the verge of becoming operational in Afghanistan's Jegdalek region today. It is

expected that, once the Afghan government issues mining licenses, some 2,000 people will return from refugee camps to work these deposits (Bowersox et al., 2009). Afghanistan's Vardak Province has produced a small amount of blue sapphires (Quinn and Laurs, 2004).

The first rubies from the Himalayan Mountains were discovered in east-central Nepal in the 1980s.

Figure 19. The Winza deposit in Tanzania has attracted the attention of serious connoisseurs because of the superb rubies it can produce. This 14.97 ct gem is courtesy of Mona Lee Nesseth Custom and Estate Jewels and a private collector, Laguna Beach, California. Photo by R. Weldon.

The Chumar and Ruyil deposits in Nepal have produced pink-to-red corundum and some violet-to-blue sapphire (Smith et al., 2007). Rubies from Tajikistan are comparable to some of the world's finest, ranging from pinkish red to red (Pardieu, 2007). Production is sporadic due to the lack of infrastructure and the high altitude of the deposit.

United States. Sapphire has been known in Montana since 1865, with significant mining since the late 19th century (see, e.g., Emmet and Douthit, 1993). Four major sources comprise Montana's alluvial sapphire deposits: the Missouri River (including El Dorado Bar), Dry Cottonwood Creek, and Rock Creek. The American Gem Corp. undertook large-scale mining efforts at Rock Creek between 1994 and 1996, producing more than four million carats of gem-quality rough—and, for a brief period, making Montana one of the world's largest sources of sapphire. This production has thus far yielded more than one million faceted gems (Kane, 2003). Today, mining operations at Rock Creek are mostly small. Montana's alluvial sapphires are often subjected to heat treatment, resulting in a variety of more marketable colors (Emmett and Douthit, 1993).

Yogo Gulch, discovered in 1895, is Montana's only primary sapphire deposit. Yogo sapphires are uniformly blue (often described as "cornflower blue") and do not need heat treatment. However, the rough typically yields small, melee sizes. Some market analysts say the material is simply not large enough to cover production costs, especially compared to other corundum sources worldwide (Austin, 2001), although the present owners believe it is sufficiently viable to continue to develop the property (Baiz, 2009).

FACTORS AFFECTING VALUE

New sources and treatments have been critical to expanding the market for ruby and sapphire to a broader base with more commercial jewelry (figure 20). However, market prices for ruby and sapphire are based on a number of interrelated factors: geographic origin, color (subtle differences in hue create large differences in price), clarity, cut quality, supply, demand, type of treatment, extent of treatment, public confidence in the product, and exchange-rate fluctuations. All of these factors have come into play during the past decade for both corundum varieties, with particular emphasis on country of origin, treatments, and cutting.

Figure 20. Greater quantities of sapphire and ruby have become available to a much larger market in attractive yet affordable jewelry (here, the ruby is 0.50 ct). Courtesy of Pauling Blue Fire Diamonds, Carlsbad, California; photo by R. Weldon.

The Significance of Country of Origin. The source of an important ruby or sapphire historically has been a critical factor in gauging its potential demand and ultimately value. In fact, international auction houses have depended heavily on laboratory determination of origin to obtain premium prices for certain rubies and sapphires (F. Curiel, pers. comm., 2008).

This has not occurred without controversy. In 1990, GIA chairman Richard T. Liddicoat wrote that the beauty of a gemstone—not its origin—should be the primary factor in determining its value. "Why should someone pay more for an inferior ruby because it came from Burma?" he asked (Liddicoat, 1990, p. 247). Liddicoat also cited the technical challenges of determining source locations with reliable certainty at that time. New sources of corundum discovered since then have underscored these challenges.

Gemstones from different locales do have characteristic features (e.g., three-phase inclusions in Colombian emeralds, rutile silk in Burmese rubies, and "sleepiness" due to inclusions in Kashmir sapphires), but difficulties arise with materials that do not exhibit telltale signs or that share features with stones from other localities—particularly in the higher qualities. Indeed, a spate of reports indicating significant overlaps of appearance and characteristics in high-quality sapphires from Sri Lanka, Myanmar, and Madagascar began to surface as

Madagascar's sapphire bounty reached markets in the mid-to-late 1990s and early 2000s (see, e.g., Roskin, 2005).

Yet demand by the trade and public to differentiate among corundum from various sources also grew during this period—perhaps precisely because such overlaps caused confusion (Roskin, 2005). As a result, requests for differentiating localities became increasingly common. More recently, the need to determine origin has been tied to political concerns, such as the U.S. government's ban on rubies from Myanmar.

Technology has also advanced in ways that make such determinations far more certain than at the time Liddicoat wrote his editorial. Today, several gemological labs around the world offer services to determine the origin of important gemstones, which they do by analyzing a combination of properties such as inclusions, trace-element chemistry, spectral characteristics, and internal growth structures (Kane et al., 2005). They also typically stress that such determinations are expert opinions only.

The Effect of Treatments on the Corundum Market. Several treatments designed to change the appearance, and thus the perceived value, of rubies and sapphires have been practiced for decades—and in some cases for centuries. Historically, sapphires and rubies have been coated with substances to enhance their color, or dipped in oil to improve apparent transparency. Such practices—as applied to a variety of gems—were described by Pliny the Second two millennia ago (Nassau, 1984). Although the coating of sapphire and ruby may not be as common today, the introduction of dyes into surface-reaching fissures is now routine, particularly in low-end beads.

More-sophisticated treatments—particularly high-temperature, atmosphere-controlled heating of corundum—are now commonplace. Combined with full disclosure throughout the supply chain, heat-treated rubies and sapphires have found their niche and price points within the market. Even this treatment, however, faced considerable controversy when it was first revealed, especially when not disclosed. The introduction of heated *geuda* sapphires, for example, seriously disrupted the sapphire trade almost 40 years ago. But once the controversy settled down, this treatment helped expand consumer demand for sapphires by making them more available and affordable to the

mass market (Drucker, 1999a; figure 20). Heating also became the stepping stone for two significant new treatments that have radically altered the appearance of corundum and its perceived value over the last decade in particular: beryllium diffusion and lead-glass filling.

Beryllium Diffusion. In late 2001, large amounts of pinkish orange "padparadscha" sapphires—represented as natural color—began to appear on the market. While prominent gemologists soon suspected a form of diffusion, there was no understanding at the time about what elements might cause the "padparadscha" and orangy colors on a consistent basis. Thorough investigation proved that a diffusion treatment was indeed being used, and that beryllium was the element being diffused at extremely high temperatures (Emmett et al., 2003). The sudden appearance of these treated sapphires (figure 21), combined with their clandestine release into the marketplace, caught gem dealers and gemological laboratories by surprise (Henricus, 2002). These stones also caused substantial disruption in the gem community, at least temporarily, because the treatment was difficult to detect (Emmett et al., 2003).

The controversy eventually reached the consumer press. A report in *The Wall Street Journal* described the new treatment as a "scandal," going on to remark that "heat treatments and additives turn lesser sapphires and rubies into facsimiles of

Figure 21. This group of beryllium-diffused sapphires (1–2 ct) is typical of the colors seen on the market. GIA Collection no. 30858; photo by R. Weldon.

Figure 22. These lead glass–filled rubies (2.47–3.18 ct) show the range of color of treated material from Madagascar. Courtesy of Real Creation, Los Angeles; photo by R. Weldon.

rare beauty" (Mazurkiewich, 2003, pp. B1 and B3). The article noted that prices quickly fell and some gem wholesalers lost $30 million. The release of these gems caused a minor disruption in the collector market as well: *All* padparadscha sapphires became suspect until the diffused stones could be reliably identified (E. Caplan, pers. comm., 2009). Today, identification of this treatment—which is applied to produce ruby-like hues as well as blue and other colors of sapphire—is straightforward. However, it often requires advanced instrumentation such as laser ablation–inductively coupled plasma–mass spectrometry to establish the presence of beryllium (a light element not detectable by more commonly used analytical techniques such as EDXRF spectroscopy).

Lead-Glass Filling. Natural cavities and surface-reaching fissures in corundum have been filled with a borax-based glass compound for at least 25 years (Kane, 1984; Peretti et al., 1995). However, a new treatment involving glass with a high lead content entered the market in the early 2000s ("Lead glass impregnated ruby. . . ," 2004). It quickly became prevalent in low-quality corundum—mostly rubies. Because of the lead glass's higher refractive index, filled fractures or cavities were more effectively concealed. Much of the starting material initially came from Madagascar's Andilamena deposit (Milisenda and Horikawa, 2006). Such low-quality cloudy pink corundum was transformed into "ruby"-red corundum exhibiting much greater transparency (e.g., Hänni, 2006; figure 22).

The filled material is readily identified with magnification (e.g., McClure et al., 2006). Low-quality, fractured material from any locality is susceptible to being treated with high-lead-content glass

(Themelis, 2000). As with diffusion treatment, it is imperative that this material be disclosed.

Cutting. Traditionally, gems have been sold by weight, but jewelry manufacturers often faced difficulty buying large parcels of gemstones because proportions from hand cutting, even among pieces of nearly identical weight, varied too widely for automated setting and jewelry casting operations. The 1990s brought new lapidary technology, in the form of computer-guided shaping and cutting, that allows for precision-cut ruby and sapphire compatible with jewelry manufacturers' mass-production requirements (Kremkow, 1997; Weldon, 2004).

One of the first precision cutters was D. Swarovski & Co., through its Swarogem subsidiary, which introduced small calibrated ruby and sapphires in 1997. These were primarily sourced from Mong Hsu (ruby) and Anakie (sapphire; Kremkow, 1997). The goods were cut in 0.25 mm increments, between 1 and 3 mm, for sale in large lots to jewelry manufacturers. Since then, other suppliers have introduced precision-cut gemstones for mass-market jewelry manufacturers—and some distinctive designers (figure 23).

Advances in cutting technology also have widened the scope of traditional gemstone shapes and styles, as evidenced by such well-publicized cutting competitions as the American Gem Trade Association (AGTA) Cutting Edge and Spectrum awards (e.g., figure 24), and the German Award for Jewellery and Precious Stones (Weldon, 2006). Finally, cutters such as Mark Gronlund, John Dyer, and Richard Homer have used concave facet cutting techniques that add brilliance, symmetry and beauty to corundum and other gem materials (Weldon, 2005; again, see figure 7), while lapidary Glenn Lehrer developed the Torus Cut, essentially a circle with concave and convex facet arrangements, which proved ideal for Montana sapphire pieces that were too flat to fashion into traditional gem shapes (Wheaton, 2000).

THE CORUNDUM MARKET TODAY

After export, most ruby and sapphire is sold through networks of small dealers and cutters who have no obligation, as public companies do, to report yearly sales. Similarly, retailers around the world, public or not, rarely separate out their sales figures for ruby and sapphire—or even colored stone jewelry.

It is safe to conclude that up to and through the 1970s, the market for faceted blue sapphire and

ruby was small relative to the quantities in the jewelry industry today, simply because supplies were limited primarily to the low percentage of facetable goods (typically less than 5%) that came from the mines in salable colors. The introduction of effective heat-treatment techniques to improve the color and clarity of previously unsalable material, such as *geuda* sapphire from Sri Lanka and dark, "silky" blue stones from Australia, greatly increased the quantities of sapphire available to the market, particularly in the lower-priced commercial qualities. A similar situation occurred with ruby in the mid-to-late 1980s after the Mong Hsu deposit was discovered (Emmett, 2007). And not only did treatments greatly increase the proportion of facet-grade material available, but they also allowed development of deposits where there was little or no naturally occurring gem-quality material (Emmett, 2007).

Recently, two market research studies have shed light on sales of colored stones in general—and ruby and sapphire in particular—at wholesale and retail. They found—not surprisingly—that corundum represents the largest single share of the colored stone market. One study, published in 2009 in Dubai, reported that the world retail market (of which the U.S. accounted for 60%) for all "precious" gemstones was approximately $80 billion: $69.7 billion for diamonds and $10.3 billion for colored stones and pearls. Of the latter amount, ruby and sapphire accounted for 30%, while emerald was 12%. The remaining 58% comprised all other gems, including pearls (BUZ Consulting, 2009).

The second study, commissioned by True North Gems, pegged the pipeline (retail sales and inventory) for ruby at $2.1 billion and sapphire at $800 million ($58 million of which was pink sapphire), for a total similar to the approximately $3 billion cited in the Dubai study. The same source noted that emerald sales totaled $1.4 billion. The sapphire share is low in comparison to that of ruby because of the large quantities of low-quality and diffusion-treated sapphire in the market (Smith, 2009).

The Dubai study (prepared before the fall 2008 onset of the global economic crisis) predicted that sales of colored stones would grow an average of 6.1% annually around the world. However, that report and other sources (Emmett, 2007; Shor, 2007c) listed a number of challenges that could hamper growth in retail demand for colored stones, including corundum:

Figure 23. New cutting technology has led to better-cut, calibrated gems for manufacturing jewelers and designers alike. This stylized butterfly pin contains invisibly set princess-cut pink, blue, and yellow sapphires. Courtesy of Michael Schofield & Co., Clear Creek, Indiana; photo by R. Weldon.

- There are no universally accepted grading standards, which makes colored stones more difficult to describe and appraise than diamonds.

- Apart from tanzanite and several varieties of pearls, there are no coordinated large-scale marketing efforts, such as those that have helped spur diamond, gold, and platinum jewelry sales.

- Supplies can be unpredictable. Colored stone deposits tend to be relatively small and sporadically distributed, and thus many have a short life span.

- The perception of the financial community is that the colored stone industry is a "Wild West" environment, with few laws and extremely fragmented markets.

- The lack of documented information about the colored stone industry deters banks and other financial institutions from offering credit lines.

- Sales of colored stone jewelry are more closely tied to fashion trends than other forms of jewelry and thus are more volatile.

Figure 24. The AGS Cutting Edge Awards promote excellence as well as innovation in gem cutting. This unheated 4.53 ct pink sapphire from Nanyaseik in Myanmar won first place in the classic gemstone division for 2010. Courtesy of Robert Kane/Fine Gems International, Helena, Montana; photo by R. Weldon.

- Treatments remain an issue, and debates continue over "acceptable" and "unacceptable" treatments.

FAIR TRADE

Consumers in many countries are developing a greater awareness of social and environmental issues surrounding the products they purchase (Shor, 2009). Many of these concerns are grouped under the term *fair trade*: a trading partnership between producers and buyers seeking greater equity in international commerce through ethical labor practices, including gender equality and safety standards, sustainable environmental practices, ethical business practices, and poverty alleviation. A number of monitoring agencies have been created to certify fair trade practices for many consumer products, with those meeting the established criteria then labeled as "fair trade" products. In the gem and jewelry industry, the Responsible Jewellery Council is developing a certification scheme for diamond and gold miners and retailers. At this time, however, no official program exists for the colored stone industry (Weldon, 2008).

Some gem dealers are paying greater attention to these needs for a fair trade system. Columbia Gem House (Vancouver, Washington) has developed a system of protocols aimed at developing accountability—both financial and human—in every aspect of its gemstone supply chain (Weldon, 2004). The Madison Dialogue, a forum of cross-sector miners, association leaders, nongovernmental organizations, and World Bank executives, met in Washington, DC, in October 2008 to discuss how fair trade and sustainability programs can be applied to the jewelry business (Madison Dialogue. . . , 2008). Since then, committee members have begun to refine common principles and develop best practice initiatives in the mining of metals as well as diamonds and other gems. Also, the International Colored Gemstone Association (ICA) has examined the issues at several of its recent congresses, and members of the organization are active in gemstone steering committees of the Madison Dialogue. Separately, ICA directors are leading initiatives in Nigeria and Greenland aimed at developing fair trade models that could be used at other gem localities around the world (J. C. Michelou, pers. comm., 2009).

Demand for fair trade products is increasingly consumer driven, and has gained traction, especially among younger consumers who tend to be more inclined to do business with companies they see as upholding positive social and environmental objectives (Cone, 2007). The same consumers also require accountability and verification along a product's supply chain, administered or audited by independent third-party verification entities.

CONCLUSION

The advent of effective treatment methods, coupled with discoveries of significant new deposits of ruby and sapphire—many of which would have been uneconomic as gem sources without such treatments—has greatly expanded the world retail market for gem corundum. As with diamonds and other gemstones, however, world events, local conflicts, and political upheavals have affected supplies and, possibly, consumer attitudes toward ruby and sapphire.

The future of the ruby and sapphire market will depend on continued discoveries of new corundum-producing deposits as existing ones wind down. Increasingly, the search for, and exploitation of, new sources will be tempered by environmental concerns and fair labor practices. As the world

becomes more connected and transparent, miners, cutters, dealers, and retailers will face increasing scrutiny. This is evidenced by the attention that governments and nongovernmental organizations have focused on the diamond and gold extraction industries.

Another key issue for the corundum industry remains both the understanding and disclosure of treatments. A number of treatments that substantially transformed low-value material have undermined trade confidence in recent years. The treatments were not disclosed upon their introduction to the market, with the result that prices for such goods, for a time, fell to extreme lows while the values of fine untreated goods rose sharply. While U.S. and interna-

tional gem trade organizations require disclosure, some retailers, concerned that customers may not understand or accept treatments, remain reluctant to disclose when selling colored stone jewelry.

The market for corundum still holds significant future potential. Several studies point to increasing consumer demand for colored gemstones, which could outpace gold and diamonds in the coming years, particularly in emerging markets. Ruby and sapphire sales at the retail level will likely be tied to consumer-driven fashion trends and consumer confidence in the product as represented. Increasingly, the consumer will also require that the product embodies positive social, ethical, and environmental values.

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CUTTING DIFFRACTION GRATINGS TO IMPROVE DISPERSION ("FIRE") IN DIAMONDS

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A new microlithography process developed to create high-resolution diffraction grating patterns on portions of certain facets can improve the dispersion of light and thus the amount of "fire" in a diamond. These Nanocut plasma-etched diamonds can be identified with magnification by the presence of small, unpolished-appearing areas on the facets where the grating pattern has been created. Round brilliant–cut diamonds displaying such patterns will be classified by the GIA Laboratory as modified round brilliants; as such, they will receive color and clarity grades, but not a cut grade.

For nearly 450 years, the diamond trade has sought to define the factors that characterize the most attractive polished diamonds. While the color and clarity intrinsic to the diamond have long been important in this regard, by focusing on proportions the merchant is able to *create* a superior visual appearance (see review in Gilbertson, 2007). When Henry Morse introduced new measurement tools in the 1870s and '80s, cutters were able to achieve more precise angles and proportions—and produce more attractive diamonds (Kunz, 1888; Leviticus, 1908). One could see "a mediocre diamond transformed into a snapping, blazing gem, full of fire, simply by being recut with a proper regard for the accuracy of the facets" ("The diamond cutting industry in America," 1894, p. 54). Today, the appearance of "fire" in a diamond—the visual manifestation of its dispersion—is considered one of the essential criteria by which the stone's overall appearance is judged (e.g., figure 1).

Quantitatively, *dispersion* is a measure of the angular separation of refracted light of different wavelengths (specifically, blue light at 430.8 nm and red light at 686.7 nm) within a given material. Diamond has a fairly strong dispersion value of 0.044. White light entering a polished diamond from most angles refracts and separates into its distinct component colors. Although the initial expansion of colors is very slight (typically less than 0.5°), the angular spread of light rays of various wavelengths widens with each facet interaction and continues to do so as the rays travel farther from the point of refraction. In other words, the more times a light ray reflects within a diamond, the greater the separation of the spectral colors—and the more obvious the appearance of fire—will be. Fire in a gemstone is best defined as "the visible extent of light dispersed into spectral colors" (Reinitz et al., 2001). In a polished diamond, this is seen as flares or flashes of color that appear and disappear as the diamond, the observer, or the light source moves.

Figure 1. The appearance of fire in a diamond has traditionally been one of the key elements in assesing the quality of its overall appearance. These Nanocut plasma-etched diamonds (0.41–0.46 ct) have diffraction gratings etched into small portions of their pavilions to enhance fire. Photo by Robert Weldon.

Ordinarily, a faceted diamond has a specific arrangement of flat facets, and light travels within it in ways familiar to diamond cutters. However, the standard faceting process is not the only way white light can be separated into its component colors. Another method is with a diffraction grating, familiar to gemologists as part of a handheld spectroscope. Joseph von Fraunhofer constructed the first diffraction grating in 1820 by tautly extending fine, parallel metal wires between two threaded rods. Fraunhofer used this device to observe emission lines in sunlight (Fraunhofer, 1899). A beam of white light incident on a diffraction grating will separate into component wavelengths based on the angle of incidence, with each beam traveling in a slightly different direction (Bragg, 1913). Because of their light-dispersive properties, diffraction gratings are used in monochromators (to produce monochromatic light) and spectrometers (to measure the properties of light at specific wavelengths; Jenkins, 1976). The extent of spectral colors diffracted from such a grating also depends on the type of incident light source (figure 2).

This article describes recent work performed by a research team at the California Institute of Technology in Pasadena, California, to influence the path of light return in a diamond—and thus enhance the perceived fire—by patterning small areas of its facet surfaces with a high-resolution diffraction grating using a proprietary, patent-pending method that combines microlithography and plasma etching (again, see figure 1). For the remainder of this article, the process will be referred to as

"plasma etching." The resulting gems are marketed by Rockoco Inc. (www.rockocoinc.com) as Nanocut plasma-etched diamonds.

MATERIALS AND METHODS

To understand the effect of a diffraction grating on diamond without the influence of facets at various angles and proportions, we first etched a series of grating patterns that radiated from a common center on the polished surface of a flat diamond crystal (figure 3). Micrometer-scale diffraction gratings were then applied to all or part of the pavilion or crown facets of 42 polished diamonds: 41 round brilliant cuts and one octagonal step cut (e.g., table 1; full data for all the diamonds are given in the *G&G* Data Depository at www.gia.edu/gandg. The pavilions of

Figure 2. Under diffused lighting (left), the diffraction grating formed by lines on the surface of a compact disc (6,250 lines per centimeter) very faintly separates white light into spectral colors. Under spot lighting (center), the same grating separates a single spot light source into distinct spectral colors, like those in a rainbow. Under an array of spot lighting (right), it separates multiple spot light sources into a myriad of distinct spectral colors. Composite photo by A. Gilbertson.
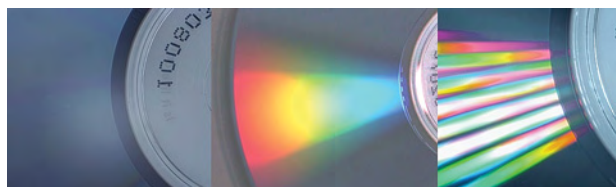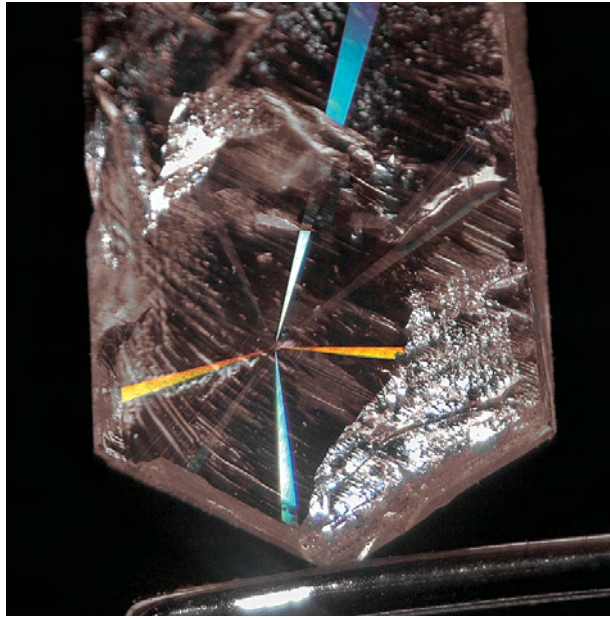
Figure 3. A radiating pattern of diffraction gratings was placed on the flat polished surface of a tabular diamond crystal. As shown here, they diffract the incident spot (fiber-optic) lighting into spectral colors. Photo by John Koivula.

the first five diamonds (0.04–0.08 ct) were covered entirely with diffraction gratings consisting of 1,000 lines per centimeter. Next, six different styles (A–F in figure 4)—each representing a different placement of a grating pattern at 5,000 lines per centimeter—were plasma etched on round-brilliant samples 6 through 41. For visual comparison, the authors used four round brilliant–cut diamonds that did not have grating patterns (RD01, RD04, RD11, and RD78), all of which were previously used in GIA's cut-grade research (see, e.g., Moses et al., 2004).

The 36 study diamonds with patterns A through F were assessed by the authors and others. These diamonds weighed between 0.37 and 0.71 ct, with color grades in the E–I range and most clarity grades ranging from VS to SI (one was I_1). We chose this size range because researchers involved in GIA's 2004 cut study found that such diamonds could be comfortably compared against each other for cut evaluation; additionally, the cut study found that observers were able to assess overall cut appearance regardless of differences in bodycolor (Moses et al., 2004). Although these observations were not a controlled study, we found the results helpful in refining our approach.

Bob Lynn, a jeweler aware of this new process, had a 2.30 ct diamond in his inventory plasma etched with pattern C and allowed us to examine it before and after the etching process. To determine if placement of a diffraction grating could improve the apparent fire in colored and/or step-cut diamonds, we also had a variation of pattern C etched onto an octagonal step-cut fancy brown diamond.

The Process. *Microlithography* is a process by which a temporary coating (called a *resist*) is deposited onto a substrate, exposed to light or an electron beam, and developed (i.e., with a solvent that selectively removes the resist) to define small patterns within the resist layer. The pattern is transferred onto the substrate by etching or by depositing another material. Microlithography is commonly used in the semiconductor industry for manufacturing integrated circuits.

TABLE 1. Plasma-etched and conventionally cut diamonds used for the visual comparison tests in this study.

Sample number	GIA cut grade[a]	Pattern style	Weight (ct)	Clarity	Color	Table %	Crown angle	Pavilion angle	Star length	Lower half %	Girdle minimum length %	Girdle maximum	Girdle %	Culet size	Polish	Symmetry
32	VG	B	0.47	SI_1	F/G	56	36.5	40.6	55	75	Thin	Medium	2.5	Very small	EX	EX
33	G	C	0.45	VS	H/I	59	30.5	40.4	50	75	Thin	Thin	2.0	None	EX	VG
37	VG	C	0.71	VS_2/SI_1	F/G	57	36.5	41.4	50	80	Medium	Medium	3.0	Very small	VG	VG
RD01	EX	None	0.61	VS_1	E	54	34.5	40.6	55	80	Thin	Medium	3.0	None	VG	VG
RD04	VG	None	0.70	VVS_2	E	59	36.0	42.0	55	75	Slightly thick	Thick	4.5	None	VG	G
RD11	G	None	0.71	VS_2	D	58	37.0	42.2	45	85	Medium	Slightly thick	4.0	None	VG	G
RD78	EX	None	0.73	VS_1	J	58	35.0	41.0	55	80	Medium	Slightly thick	4.0	None	VG	VG

[a]Equivalent GIA cut grades are used for the plasma-etched diamonds, based on proportions, polish, and symmetry. In practice, plasma-etched diamonds do not receive GIA cut grades. Abbreviations: EX = Excellent, VG = Very Good, and G = Good.
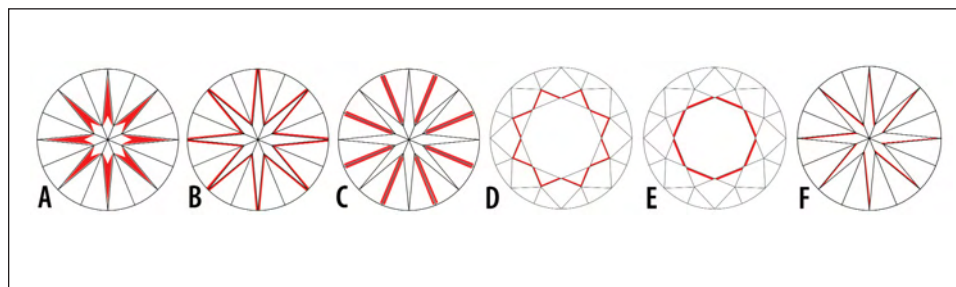
Figure 4. Six diffraction grating pattern styles were developed in the course of this study. The placement of the gratings on specific areas of the pavilion or crown facets is shown here in red.

NEED TO KNOW

- A new process combining microlithography with plasma etching creates microscopic diffraction gratings on selected facets of a diamond.

- Properly applied, these diffraction gratings can increase the apparent fire in spot and mixed lighting.

- The best results were obtained by applying the gratings to areas of pavilion facets that would otherwise appear dark face-up.

- Nanocut plasma-etched diamonds will not receive cut grades from GIA.

Plasma etching is the process of eroding material from the surface of a solid by bombarding it with particles of ionized gas. Unlike chemical-etching processes, plasma etching allows anisotropic removal (i.e., preferentially along one direction), where the pattern depth is controlled entirely by the processing time. Oxygen plasma etching is commonly used to prepare samples prior to examination by electron microscopy, and pure carbon can be removed at rates well over 100 nm per minute. This method has been refined to the point where it can create structures smaller than the wavelength of visible light (as small as 100 nm).

Steps in Creating a Diffraction Grating on a Polished Diamond. First, the diamond must be carefully cleaned by soaking it in a solvent and then boiling it in sulfuric acid. Next, the diamond is centered table-down on a silicon wafer and held in place using a polymer adhesive. A proprietary coating material, the resist, is placed on the diamond. The stone is spun at a high speed to coat the pavilion uniformly, and then heated to bake the resist onto the surface (figure 5).

Once coated with the resist, the diamond is placed in a vacuum chamber (figure 6) and precisely aligned so that the grating can be located in the exact pattern and position required. After the select-

ed pattern (see the computer screen on the left of figure 7) is centered, an electron beam is directed across the surface within the pattern outline. The beam changes the chemical composition of the resist (Wells et al., 1965; Wolf et al., 1970), so that a chemical developer can be used to dissolve only the altered portions and expose the area where the lines of the grating will be etched. This leaves a residual etch mask of the pattern, with the resist covering the remainder of the pavilion surface (figure 8).

The diamond is then placed in a second closed chamber for plasma etching (Pan, 1994). Oxygen gas is introduced into the chamber, where the oxygen molecules are ionized by an electromagnetic field and react with the exposed areas of the diamond to form carbon dioxide gas. This etching process takes only a few seconds, and the grating pattern is created on the portion of the diamond not covered by the resist (figure 9). After etching, the diamond is placed in an acid bath to remove the residual resist.

Currently, the entire process takes five hours per diamond. Scanning the electron beam is the most time-consuming step, since considerable alignment is necessary to stabilize the beam and center the diamond, and the high-vacuum chamber must be cycled each time it is opened. However, the actual scanning time is only a few minutes. Likewise, the plasma etching is performed in a vacuum system that has lengthy pump-cycle times, uses gas lines that need to be purged before and after etching, and requires peri-

Figure 5. After cleaning, a diamond (here, ~0.5 ct) is first cemented onto a silicon wafer and coated with a resist (left). After the resist has been baked on the facet surfaces, the coated diamond is ready for further processing (right). Photos by Robert Weldon.
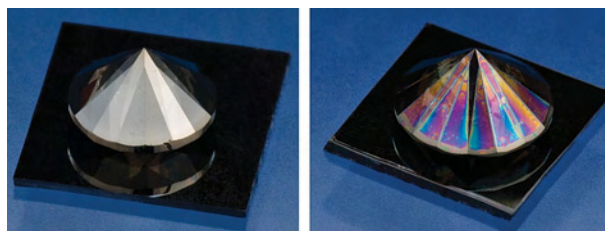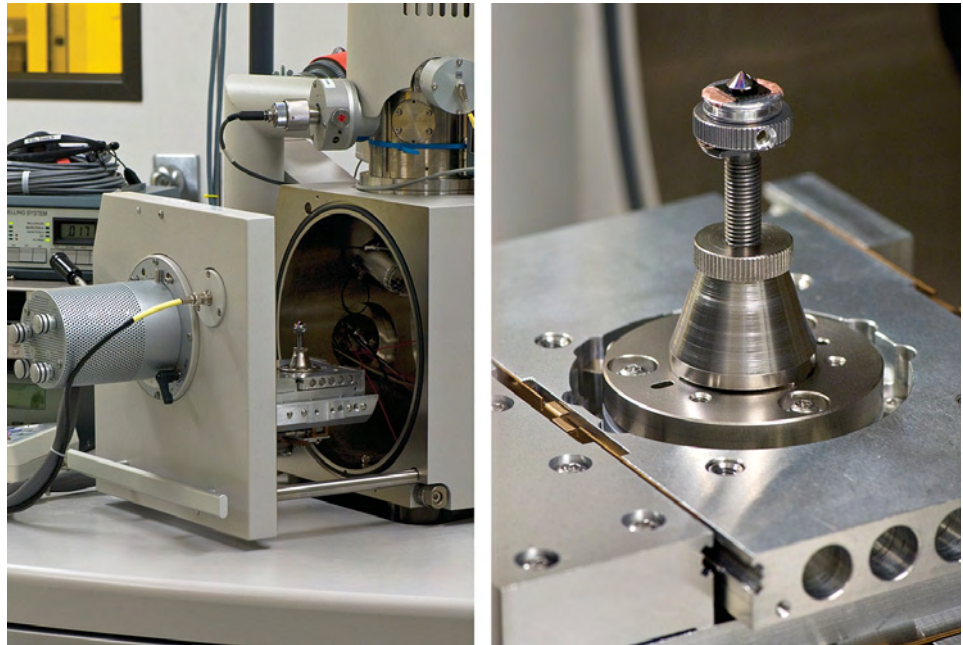
Figure 6. The coated diamond is placed inside a chamber (left) where an electron beam etches a pattern into the resist. The diamond is carefully aligned on the stage of the chamber (right). Photos by Robert Weldon.

odic chamber cleaning. The complete scanning and etching processes each take about 90 minutes.

A diffraction grating can be applied to facets on diamonds of any size or shape. During this study, several refinements were made to the fabrication process to improve the appearance of light dispersion (e.g., changing the number of etched lines in the grating and the targeted portion of the pavilion, and tuning the plasma to minimize the roughness of etched areas). While the goal of this study was to

Figure 7. The operator oversees the careful patterning of the electron beam on the diamond. The computer monitor on the right enables the operator to view and control the alignment, and the one on the left shows the pattern to be etched. The sample chamber is at the far right. Photo by Robert Weldon.

produce faceted diamonds with more fire, further modifications could make it possible to produce other optical effects. Although similar gratings can also be applied to other polished gems, the method described here is most suitable for carbon-based materials, especially diamond due to its relatively pure chemical composition.

Visual Comparison Tests. Our ultimate goal was to determine if there was a diffraction grating pattern that could be placed on diamonds of commercial cut quality (such as GIA Good or Very Good cut grades) that would improve their appearance in spot or mixed lighting environments. After evaluating the results from the first five stones (plasma etched over their entire pavilions at 1,000 lines per centimeter), we had a group of 26 diamonds of various proportions (diamonds 6–31; again, see the *G&G* Data Depository) etched with a grating of 5,000 lines per centimeter using pattern A in figure 4. This enabled us to see how diffraction gratings affected face-up appearance across a broad range of proportions. We carefully looked at these plasma-etched diamonds in the diffused, spot, and mixed lighting of the DiamondDock (as described in King et al., 2008), comparing them to the four conventionally cut diamonds. The DiamondDock's spot lighting was set at approximately half power for the mixed lighting and spot lighting observations; the intensity of spot lighting can vary within mixed

lighting environments. We used the same gray stone trays as in the 2004 cut study, and observation distances varied by user (from approximately 10 to 20 in. [25–50 cm]).

On the basis of these observations, we modified the original pattern A (again, at 5,000 lines per centimeter) and applied various modifications to a further set of diamonds (nos. 31–40) to achieve a better balance of fire and overall appearance, resulting in a total of five additional grating patterns (again, see figure 4). We made further comparisons to the conventionally cut diamonds in terms of overall appearance in different lighting environments, and also asked random observers who were *not* experienced in assessing overall diamond appearance (referred to here as outside observers) to make similar observations.

For example, we asked 10 outside observers to look at a set of seven diamonds: four conventionally cut (RD01, RD04, RD11, and RD78; cut grades Excellent, Very Good, Good, and Excellent) and three with diffraction gratings (nos. 32, 33, and 37; cut grades Very Good, Good, and Very Good; again, see table 1). We then asked the observers to rank their top three visual preferences in each of the same three lighting environments, with 1 as best. The four diamonds that were not selected were each given an average ranking of 5.5 (the average of 4, 5, 6, and 7). As noted above, our experience during GIA's cut study was that variations in size (such as 0.40–0.90

ct), color (D to beyond L), and clarity (SI or better) did not influence visual judgment of cut quality. The observers' occasional comments about overall appearance also provided useful information.

One important question we hoped to answer was whether a diamond that had been cut-graded as Very Good (no. 37) could be improved by the plasma-etching process, so that it would equal or exceed the appearance of a conventional diamond with an Excellent cut grade (RD01). To this end, we carefully compared these two diamonds in the Diamond-Dock in each of the three lighting conditions. Both diamonds were placed in light gray trays (like those used in the 2004 cut study) that could be held at a comfortable distance and moved as necessary. A different group of observers (again, without experience in assessing overall diamond appearance) were asked to indicate which diamond they preferred.

Other Tests. To test the durability of the plasma-etching process, we placed several diamonds with diffraction gratings together with other diamonds in a ball mill and tumbled them for one week. We then examined their surfaces with a scanning electron microscope (SEM) to detect signs of damage. We also weighed sample no. 42 before and after plasma etching to determine if there was any detectable weight loss.

RESULTS

Experiments to Enhance Fire. We first wanted to see if fire could be improved with the application of a diffraction grating pattern on all or part of certain facet surfaces. Under spot lighting, the tabular dia-

Figure 8. The resist covers the entire pavilion surface. The electron beam emitter moves in parallel lines (black, left) above the diamond, and as it moves, the electron beam traces these lines onto the diamond surface within the area of the selected pattern outline (red). The chemical composition of the resist is altered by the electron beam only in the pattern areas. Those areas are chemically dissolved, and the underlying portions of the facets are left exposed to allow a small amount of diamond to be removed by plasma etching (center). The photo on the right shows a diamond after the electron beam has left a pattern on the resist. Arrows indicate the altered portion of the resist. Photo by Robert Weldon.
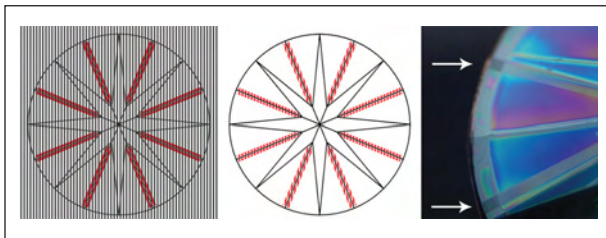
Figure 9. This SEM image shows the parallel etched lines of the diffraction grating on a diamond surface. Image by B. Gudlewski.
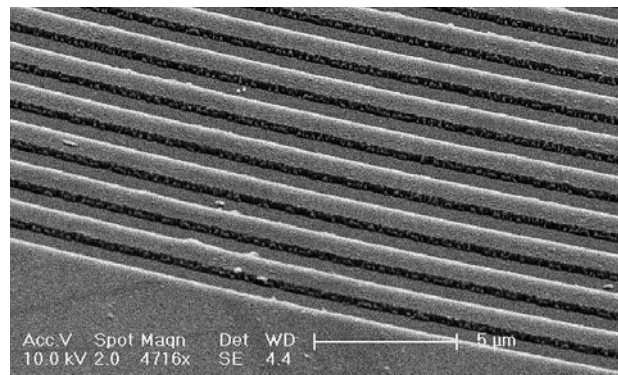
Figure 10. The grating pattern covers the entire pavilion of this 0.07 ct diamond. Modifying all the facet surfaces caused a reduction in overall brightness under diffused light (left). When examined with spot lighting (right), the diamond has an opalescent appearance and appears to be dirty or oily. Photos by Robert Weldon.
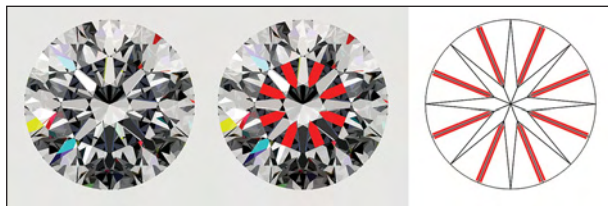

Figure 11. The grating patterns on the pavilion of this diamond (at 10×) cover too much of the areas that normally reflect white light. This experimental pattern (A in figure 4) improved fire, but the overall appearance of the diamond was not as bright, and the contrast pattern was greatly diminished. Note that even though the diffraction grating creates spectral colors (inset at 30×), the individual lines of the grating pattern cannot be seen, and areas that have been etched could be mistaken for unpolished or poorly polished facets. Composite photo by Robison McMurtry.

mond crystal we started with displayed fire from the radiating features (again, see figure 3). This was best seen from less than 10 in. (25 cm) away; it was not as dramatic at greater distances. Even with the extreme case of a tabular piece of diamond, however, a diffraction grating could generate attractive patterns of light dispersion.

The five diamonds (nos. 1–5) with a diffraction grating over their entire pavilions showed a modest improvement in fire, but the overall appearance was not pleasing. Modifying the entire pavilion with a grating pattern significantly diminished both the overall return of white light and the light-dark contrast pattern between adjacent facets, producing a somewhat dull, opalescent appearance, even with spot lighting (figure 10).

Although the 26 diamonds that received pattern A (nos. 6–31; again, see the *G&G* Data Depository)

showed marked improvement in fire and overall appearance compared to the previous test pattern, the result was still not satisfactory (figure 11). We observed that the diamonds were brighter than those in the initial group, but they were still duller than conventionally cut diamonds. We subsequently determined that this was due to placement of the diffraction patterns on facets that normally would have been seen as bright.

The experiments with modified grating patterns yielded what the authors observed to be the optimal pattern: C, used on samples 33 and 37. Pattern C was designed to brighten the face-up appearance by placing the diffraction grating on areas of the pavilion that would otherwise appear slightly dark when the stone was viewed face-up (figure 12). Typically, the strong reflection of white light from the larger facet surfaces leads to a preferred face-up appearance (e.g., figure 13). By placing a small grating pattern on facets that did not interrupt the large areas of white-light return (a problem discovered with the first group of 26), we found that fire could be improved in areas that are usually darker under both spot and certain mixed lighting conditions without diminishing the brightness of the stone (figure 14).

Comparison Tests. For the first comparison test, which assessed overall appearance, we observed that the four conventionally cut diamonds had the

Figure 12. The virtual image on the left illustrates a diamond's pattern of dark and light areas when viewed in a mixed environment of diffused and slight spot lighting. The virtual image in the center and the diagram on the right show (red) the portions of the pavilion surface that were etched with a diffraction grating for pattern C, the optimal result. Modifying these areas on the pavilion results in the removal of some of the darker regions of the diamond's face-up pattern, which are then replaced with areas that display spectral colors. Photo by Robison McMurtry.

Figure 13. This 2.30 ct diamond originally had a GIA cut grade of Excellent, as shown here in diffused light (top left) and spot lighting (top right). In both environments, there is little fire. After processing with pattern C, it looks much the same in diffused light (bottom left) but has a more dynamic face-up appearance in spot lighting (bottom right). Courtesy of Bob Lynn, Lynn's Jewelry Studio, Ventura, Calif.; photos by Robert Weldon.

best appearance in diffused lighting. In mixed lighting, however, the diamonds with pattern C looked bright and well balanced, but more fiery, with a better overall appearance. While pattern B (no. 32) did not improve a diamond as much as C, the stone was still attractive. As figure 15 indicates, all three of these Nanocut plasma-etched diamonds performed better and were more fiery than the conventionally cut diamonds in spot lighting. The first group of outside observers agreed with our assessments. Although based on a small sample of diamonds, these results indicate that creating small grating patterns can significantly enhance appearance in spot lighting, and may even improve overall appearance in mixed lighting.

For the question regarding the potential for plasma etching to improve the appearance of a diamond the equivalent of one cut grade, as expected plasma-etched no. 37 (Very Good) was less attractive than conventionally cut RD01 (Excellent) in diffused lighting, but it looked much better than RD01 in spot lighting. In mixed lighting, we felt these were about the same (an improvement for no. 37 from before it was etched). When the second group of outside observers looked at the two stones in the DiamondDock, they agreed with our findings: 8 of the 10 preferred RD01 in diffused light, but 9 of the

10 preferred no. 37 in spot lighting, with no real preference in mixed lighting. In both mixed and spot lighting, outside observers noted an increase in fire.

Durability of the Diffraction Gratings. During the course of this study, we found that the most effective placement of the diffraction grating was on the pavilion, which has a relatively low risk of damage in the course of normal jewelry wear. Nevertheless, examination with the SEM revealed that tumbling did not damage the narrow grooves of the grating; nor did we see any alteration in the diamonds' appearance.

Figure 14. These two diamonds of similar proportions, one cut conventionally (RD01, left) and the other with pattern C (no. 32, right), are shown in three lighting environments: diffused (top), mixed (center), and spot lighting (bottom). When spot lighting is substantial, careful placement of the diffraction grating can improve the appearance of certain diamonds by making them more fiery. Photos by Robert Weldon.
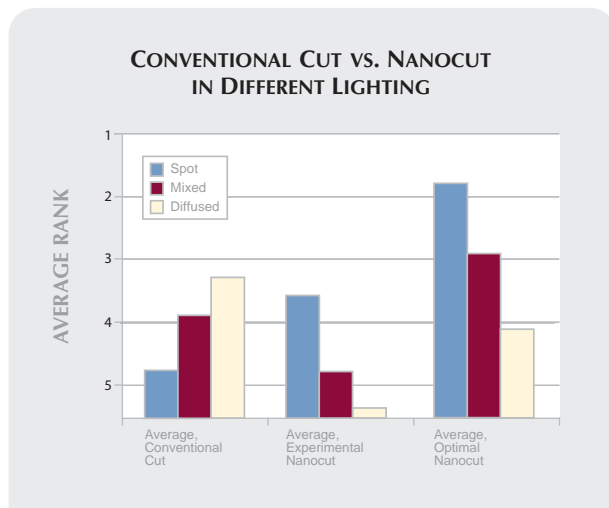
Figure 15. When a group of outside observers compared a set of four conventionally cut diamonds to three diamonds with diffraction gratings on their pavilions in a DiamondDock, they ranked the conventionally cut diamonds highest in diffused light, but the plasma-etched diamonds (nos. 32, 33, and 37) highest in spot lighting. They all noted an increase in fire seen in spot and mixed lighting.

The diffraction gratings can best be removed by repolishing the diamond (but this will also result in some weight loss).

Weight Loss. We predicted that the weight loss from plasma etching would be less than 0.001%. While we did not weigh all the diamonds before and after plasma etching, we did weigh the fancy brown octagonal cut (no. 42) with a modified pattern C diffraction grating. It went from 0.71325 ct to 0.71324 ct, a negligible difference that falls within normal measurement error.

DISCUSSION

Lighting. Various types of lighting and lighting environments produce different appearances for the same diamond. GIA's cut study found that most manufacturers and diamond dealers commonly use (diffused) overhead fluorescent lights and/or desk lamps with daylight-equivalent fluorescent bulbs to cut diamonds or evaluate the quality of diamond cutting in general (Moses et al., 2004). The authors also noted, though, that this type of diffused lighting suppresses the appearance of fire; as a rule, then, retail environments provide spot or point source lighting (often with some overall diffused lighting as well) to accentuate fire.

Diffused Lighting. A faceted diamond's appearance depends on several factors: clarity, color, quality of finish, arrangement of facets, proportions, lighting, and how the diamond is positioned relative to the observer. At a normal viewing distance (10–20 in. from the eyes) in a diffusely lit environment, the reflection of the observer's head and upper torso (seen as dark areas by the observer due to contrast with the lighting environment) combines with light leakage from the pavilion facets to cause dark areas in the reflection pattern (Harding, 1975; Moses et al., 2004). With motion, the light reflection pattern and accompanying sparkle comprise the traditional aspect of scintillation. Additionally, Moses at al. (2004) found that the dynamic or static pattern of light return is critical to face-up appearance, with an attractive diamond having a balance of dark and light areas.

If diffraction gratings are etched onto facets that are normally reflected as the white portions of a face-up pattern (dynamic or static), less of this bright light is returned. Consequently, brightness suffers when these diamonds are observed in diffused light. In contrast, etching the areas usually seen as dark reflections makes them appear somewhat brighter. Although for the most part the conventionally cut diamonds were perceived to have a better overall appearance in diffused light than the plasma-etched stones, some of the authors and outside observers indicated that in diffused lighting they perceived a slight improvement in the diamonds etched with pattern C.

Spot Lighting. In most conventionally cut diamonds, fire is observed as either small ("pinpoint") or large flashes of spectral colors. During GIA's observation testing (conducted from 2001 to 2004; Moses et al., 2004), some observers preferred pinpoint fire, while others preferred broader color flashes. The fire observed in the plasma-etched diamonds was perceived by the authors and outside observers as pinpoint flashes, with many small flashes happening at the same time, regardless of how much the diamond was moved.

Pinpoint fire is too subtle to be easily noticed in diffused lighting environments, but it is readily apparent with spot lighting, especially in an environment with relatively dark surroundings. The stronger the contrast between the spot lighting and the ambient environment, the more dramatic the fire appears to be. In this study, we found that the diamonds cut with diffraction grating pattern C

Figure 16. This octagonal step-cut fancy brown diamond (0.43 ct) is shown face-up in diffused light (top left) and spot lighting (top right) prior to plasma etching. In both instances, there is little fire. After processing with a modified pattern C adapted to this shape, the diamond looks much the same in diffused light (bottom left) but has a more dynamic face-up appearance and obvious fire in spot lighting (bottom right). Photos by Robert Weldon.

were consistently perceived to have more fire than their conventionally cut counterparts, although two of the outside observers commented that they preferred broad flashes of fire.

Mixed Lighting. Most people work and live in either diffused or mixed lighting; only occasionally does spot lighting dominate. When a diffraction grating was applied without regard to face-up pattern (i.e., figure 4A), the authors found the resulting diamond to be less attractive in mixed lighting. Conversely, with a grating applied to improve the face-up pattern (figures 4C and 16), as in no. 37, observers found the diamond to be clearly more attractive than comparable diamonds without diffraction grating.

Other Considerations. Step-cut fancy-color diamonds typically have little dispersion, either in diffused or spot lighting, and it is the novelty of the cut or the heightened color of the diamond that appeals to consumers. The authors noted that diffraction grating patterns added fire to this type of diamond when observed with spot lighting, though they made little difference with diffused lighting (figure 16).

Identifying Nanocut Plasma-etched Diamonds. The simplest method to identify plasma-etched diamonds is to examine the pavilion facets with at least 10× magnification. A facet modified with the diffraction grating will appear unpolished, and spot lighting reflected through or back from the grating will be observed as dispersed colored light (again, see figure 11).

Grading. GIA does not provide cut grades for plasma-etched diamonds. Diamonds with these diffraction grating patterns will be described as having "plasma-etching features" in the comments section of their grading reports.

CONCLUSION

Microlithographic and pattern-transfer etching techniques common in the semiconductor industry were used to create high-resolution diffraction grating patterns on specific facets of several diamonds. With careful optical modeling to determine the precise positions and dimensions of the diffraction gratings, we were able to modify light reflection and refraction from the diamond to induce additional spectral dispersion and, consequently, a more fiery appearance in both mixed and spot lighting. To minimize reduction of brightness, we selected facets for modification that otherwise would have resulted in dark areas seen face-up.

These preliminary results introduce a new approach to cutting diamonds: plasma etching. At this point, it is only being applied to enhance fire in conventionally cut diamonds. A new company, Rockoco Inc., has introduced this cutting style under the Nanocut trademark.

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CHRYSOPRASE AND PRASE OPAL FROM HANETI, CENTRAL TANZANIA

James E. Shigley, Brendan M. Laurs, and Nathan D. Renfro

Commercial quantities of gem-quality chrysoprase and green prase opal (nickel-bearing chalcedony and common opal, respectively) have been recovered from altered serpentinite deposits near Haneti, Tanzania. Material studied for this report came from the largest mine, located on top of Iyobo Mountain, which has been actively exploited for two decades. Although somewhat similar in color and appearance, chrysoprase and prase opal can easily be distinguished from one another by differences in refractive index (~1.55 vs. ~1.45) and specific gravity (~2.60 vs. ~2.11). Chrysoprase makes up the vast majority of the output, and the mine shows good potential for continued production.

Chrysoprase and prase opal are nickel-containing green varieties of chalcedony and non-play-of-color (common) opal, respectively. Both have been used as gem materials for thousands of years. Chrysoprase was described as being the "most prized" type of chalcedony by Webster (1994, p. 233). Central Tanzania is an important contemporary source of both these gems. The Tanzanian materials were first briefly described by Gübelin (1975, pp. 76–78) and Schmetzer et al. (1976). These reports were followed by a characterization of the green prase opal by Koivula and Fryer (1984), and a more detailed study of the chrysoprase by Kinnunen and Malisa (1990).

This article briefly describes the geology, mining, and gemological characteristics of high-quality Tanzanian chrysoprase and prase opal from the Iyobo Mountain mine near Haneti (figure 1). This mine is operated by Dimitri Mantheakis, who hosted two of the authors (JES and BML) there in May 2008. Although both materials have also been found in several other parts of the world (table 1), Tanzania is probably the most important source of chrysoprase after Australia.

BACKGROUND

The green color of chrysoprase has long been thought to be caused by one or more submicroscopic green nickel compounds (as Ni^{2+}). While this idea has been discussed for more than two centuries, the exact nature of these nickel compounds continues to be debated (Natkaniec-Nowak et al., 1989). Some researchers suggested it was a nickel oxide (possibly the mineral bunsenite; see Heflik et al., 1989), but subsequent spectroscopic and high-magnification imaging studies disproved this idea (see Rossman, 1994; Gaweł et al., 1997). Most others have ascribed the coloring agent to layered or framework hydrated nickel silicates (such as kerolite) or nickel-containing clay minerals (such as garnierite, lizardite, or saponite; see Rossman, 1994, pp. 458–459; Nagase et al., 1997; Dyrek et al., 2001; Sachanbiński et al., 2001; Sojka et al., 2004).

The nickel compound(s) occur as tiny, colloidal particles that are dispersed as inclusions throughout the host silica matrix. The presence of a small amount of iron (as Fe^{3+}) can modify the color of chrysoprase to be more yellowish green, whereas light scattering from microdefects or small particles in the translucent material (the "Tyndall Effect") has been suggested as the cause of the more bluish green

Figure 1. Tanzanian chrysoprase (left, cabochons ranging from 3.72 to 18.42 ct) and prase opal (inset, 35.82 ct) are commercially mined from one deposit near Haneti. All but the pieces of rough were examined for this study. Gift of Dimitri Mantheakis; GIA Collection nos. 37910–37914 (right) and 37909 (inset). Photos by Robert Weldon.

appearance seen in reflected light (Sachanbiński et al., 2001). Gaweł et al. (1997) studied chrysoprase from several localities, and concluded that those samples with a lower degree of crystallinity tended to have higher nickel contents and a more intense green color. Presumably, dispersed particles of nickel-containing minerals also color the green prase opal from Tanzania, since the visible spectra of both materials are similar (see Results section). Schmetzer et al. (1976) described this material as being opal-CT.

Because of their opaque-to-translucent green appearance and ability to take a good polish, both chrysoprase and prase opal have been used as substitutes for jade. Dyed green agate and green glass have occasionally been used to imitate chrysoprase (O'Donoghue, 2006). Also known is a chromium-colored green chalcedony found in Australia, Bolivia, and Zimbabwe (material from the last has been referred to as *mtorolite*; see Phillips and Brown, 1989; Hyršl and Petrov, 1998; Hyršl, 1999; Willing and Stocklmayer, 2003). An opaque-to-semitranslucent yellow-green carving material from Australia,

sold under the name "lemon chrysoprase," has been described as a rock consisting of magnesite and quartz (Johnson and Koivula, 1996) or of both minerals along with chrysoprase (Henn and Milisenda, 1997). All these other materials have gemological properties that allow them to be distinguished from chrysoprase and prase opal.

OCCURRENCE AND DESCRIPTION OF THE TANZANIAN MATERIAL

Location. Chrysoprase has been found on three adjacent hills that lie ~12 km southeast of the village of Haneti and 12 km north of the village of Itiso. Haneti is 75 km north of Dodoma along Highway A104 (figure 2). The mine operated by Mr. Mantheakis is located near the top of the southernmost of the three hills (known as Iyobo Mountain; figure 3), at 5° 31.90′ S, 35° 59.33′ E and at an elevation of 1,452 m. The area is accessible during the dry season (which runs April through November) by a dirt road from Dodoma to Haneti, and from there to the mine site by a rough dirt track.

Geology. According to Kinnunen and Malisa (1990), rocks in the area of the Haneti deposit are of Archean age and consist of metamorphosed ultramafics that form the three chrysoprase-bearing hills. These are aligned in a northwesterly direction, which marks the orientation of regional fracture/shear zones. They described the dominant rock type hosting the chrysoprase as a silicified and ferruginized (silica- and iron-altered) serpentinite.

TABLE 1. Other world sources of chrysoprase and prase opal.

Locality	Geologic setting	Reference
Chrysoprase		
Marlborough, Queensland, Australia	Weathered and lateritized serpentinites or other ultra-mafic rocks	Brooks (1965), Krosch (1990), Jones (1992), O'Brien (1997), Brown (2000), Downing (2007), Osmond and Baker (2009)
Warrawanda, Western Australia	Weathered and altered serpentinites associated with granites	Nagase et al. (1997)
Yerilla Station, Western Australia	Veins in weathered siliceous ironstones	Jones (1994a,b), Brown (2000)
Niquelandia, Goiás, Brazil	A galena mine (?)	Kammerling et al. (1990)
Saxony, Germany	Not reported	Wittern (2001)
Niigata Prefecture, Honshu, Japan	Not reported	Mindat.org (2009)
Sarykul Boldy, Kazakhstan	Nickel deposit in weathered serpentinite	Sachanbiński et al. (2001)
Ambatondrazaka, Madagascar	Not reported	Behier (1963)
Szklary, Lower Silesia, Poland	Nickel deposit in weathered serpentinite	Drzymała and Serkies (1973), Niśkiewicz (1982), Heflik et al. (1989), Sachanbiński et al. (2001)
Southern Urals, Russia	Not reported	Mikhailov (2000)
Tulare County, California, United States	Not reported	O'Donoghue (1995)
Various sites in Arizona, California, Colorado, Massachusetts, New York, North Carolina, Oregon, Rhode Island, and Vermont	Not reported	Mindat.org (2009)
Prase opal		
South Bohemia, Czech Republic	Not reported	Duda et al. (1991)
Silesia, Poland	Not reported	Drzymała and Serkies (1973), Webster (1994)
Southern Urals, Russia	Small vein at a "chrome mine"	Mikhailov (2000)
Napa County, California, United States	Not reported	"Prase opal in California," 1936

Figure 2. The Haneti chrysoprase and prase opal mine is located in central Tanzania, between Dodoma and Arusha.

Both the chrysoprase and prase opal occur in discontinuous veins up to several centimeters thick and several meters long in the weathered host rock. According to Mr. Mantheakis, the chrysoprase veins appear to be more abundant on the western side and upper portions of Iyobo Mountain; some areas have almost no such mineralization. Within a vein and between different veins, the material can vary from high-quality translucent to low-quality opaque. The best chrysoprase occurs in those areas of a vein that are surrounded by red clay or soil, while poorer-quality material is found where the vein is enclosed by yellowish material. The best-quality prase opal is found in veins within very brittle host rock.

Mining. Although at one time some Ni-rich magnesite veins were prospected in the region, the only mining in the Haneti area has been for chrysoprase-

NEED TO KNOW

- Chrysoprase and green prase opal are nickel-bearing green chalcedony and common opal, respectively.
- They have been mined from Iyobo Mountain near Haneti, Tanzania, for more than two decades.
- They are found in veins hosted by altered serpentinite.
- Typically, 7–10 tonnes of "mine-run" chrysoprase is produced annually (3% suitable for cabochons).
- In the past decade, ~1.5 tonnes of "mine-run" prase opal was produced.

Figure 3. The mine workings are situated on top of Iyobo Mountain and are marked by a row of tailings. Photo by B. M. Laurs.

and prase opal for both gem and ornamental purposes (Kinnunen and Malisa, 1990). According to Mr. Mantheakis, chrysoprase was first found there in the early 1960s, and limited production took place before the concession was nationalized by the government in 1973, after which the mine lay dormant. Mr. Mantheakis, a Tanzanian citizen, reclaimed the mine in 1986, and in 1997 was given full mining rights on the property.

Mining is currently carried out in an open pit (figure 4) at the top of Iyobo Mountain. As many as 35 local people are employed during the dry season. So far, 28 pits have been mined on the mountain, ranging from ~20 to ~250 m². Mechanized equipment is used to expose areas containing the gem-bearing veins, which are then excavated with hand tools (figure 5). The miners follow the veins until they pinch out (figure 6), and the chrysoprase and prase opal are collected by hand (figure 7) and placed into bags for transport to a sorting facility on site.

The chrysoprase production is highly variable, ranging from as little as 100 kg to as much as 1,000 kg per month; the typical annual production is 7–10 tonnes. These quantities are for "mine-run" rough, which includes some chrysoprase in matrix. After sorting and trimming, ~20–30% of the chrysoprase is marketable, but only 3–5% is of high quality (i.e., translucent, with even, intense color, and suitable for cutting attractive cabochons). The prase opal is much less abundant: In the past decade it has been recovered from only two areas of the mine, which yielded a total of ~1.5 tonnes of opal in matrix.

The better-quality material is sent to Dar es Salaam for trimming and polishing into cabochons. Some of the lower-quality rough is worked into beads. The material is sold through wholesale and retail outlets in Dar es Salaam, as well as through international trade shows.

Figure 4. Open-pit mining for chrysoprase and prase opal is performed using an excavator and hauling vehicle. Photo by B. M. Laurs.

Figure 5. Shovels, pry bars, and picks are used to follow the gem-bearing veins. Photo by B. M. Laurs.

Mr. Mantheakis (pers. comm., 2008) reported that his mining plan is sensitive to the local environment. He places roads to preserve as many of the large trees as possible, and most of the pits are buried as mining proceeds. He estimates that 80% of the deposit remains to be mined.

MATERIALS AND METHODS

For this study, we examined nine chrysoprase samples (five cabochons [3.72–18.42 ct] and four pre-formed or rough pieces weighing up to 8.6 g), and five prase opal samples (one 35.82 ct cabochon and four pre-formed or rough pieces weighing up to 7 g). All are representative of the better-quality material being produced from Mr. Mantheakis's mine. We documented all the samples with a refractometer, gemological microscope, polariscope, desk-model spectroscope, Chelsea color filter, and standard ultraviolet (UV) lamps.

All the samples were also analyzed by each of the following methods. Qualitative chemical analyses were performed using a Thermo ARL Quant-X energy-dispersive X-ray fluorescence (EDXRF) system with multiple filter, voltage, and current settings appropriate to the elements of interest. Ultraviolet-visible–near infrared (UV-Vis-NIR) absorption spectra were recorded over an interval of 250–2500 nm with a Perkin Elmer Lambda 950 spectrometer, using a slit width of 2 nm and a data sampling interval of 0.5 mm. (Only the 400–700 nm region is shown in the results, since this is the region of greatest interest for investigating the origin of color.) Infrared spectra were recorded over the 6000–400 cm^{-1} range with a Thermo Nicolet Magna-IR 760 spectrometer, using a 6× beam condenser at a resolu-

tion of 4 cm^{-1} and 128 scans per sample to improve the signal-to-noise ratio. We obtained Raman spectra for both materials using a Renishaw InVia Raman microscope with 514.5 nm laser excitation.

Figure 6. This vein at the chrysoprase/prase opal mine ranges from light green to deep green toward where it pinches out. Photo by B. M. Laurs.

Figure 7. The veins of chrysoprase (shown here) and prase opal typically must be trimmed from the host matrix. Photo by B. M. Laurs.

RESULTS AND DISCUSSION

Gemological Characteristics. Samples of both materials were light to medium-dark slightly bluish green and opaque to translucent; all displayed a vitreous polish luster. In general, the prase opal was slightly more translucent than the chrysoprase. The color distribution in both materials appeared uniform or very slightly blotchy. In addition, the prase opal displayed small, dark, granular brownish areas along fractures that Raman analysis indicated were most likely goethite; each of these areas tended to be surrounded by a small halo where the adjacent prase opal was yellower (figure 8). The observation that the outline of the halos followed the shape of the dark areas suggests that iron from these inclusions permeated the surrounding prase opal.

The RI and SG values of all tested samples fell within the following ranges, which readily separate the two materials from the Haneti locality:

Chrysoprase	RI	1.549 (±0.002)
	SG	2.57–2.63
Prase opal	RI	1.455 (±0.004)
	SG	2.09–2.13

Kinnunen and Malisa (1990) reported similar RI and SG values for the chrysoprase from the Haneti area. These RI values are slightly above those of chalcedony in general, but the SG ranges are consistent with those reported for chrysoprase in the literature (Webster, 1994, pp. 252–253). We could not find properties for prase opal in the literature, but the RI and SG values of our samples fell within the ranges given for opal in general by O'Donoghue (2006).

All samples were inert to both long- and short-wave UV radiation. They exhibited an aggregate reaction when viewed with a polariscope; this reaction was more pronounced for the prase opal. Neither material displayed any reaction when viewed with a Chelsea color filter (i.e., all samples remained green). The desk-model spectroscope revealed broad absorption below ~450 nm and above ~650 nm in both materials. These two regions of absorption were more intense, and the intervening region of light transmission narrowed in wavelength range, for the more saturated green samples of both materials. No sharp absorption lines were observed in the spectra of either material.

The gemological properties of both the chrysoprase and prase opal were generally consistent with reports in the literature for samples from the Haneti area and elsewhere. Kinnunen and Malisa (1990) characterized the chrysoprase as displaying a distinct microtexture consisting of disordered silica spherules (~40–80 μm diameter), formed of concentric layers of quartz, chalcedony, and opal-A, within a silica

Figure 8. This dark inclusion (probably goethite) is surrounded by a yellowish green halo. It appears that iron from the inclusion permeated the surrounding prase opal. Photomicrograph by J. E. Shigley; magnified 15×.

VISIBLE-RANGE ABSORPTION SPECTRA
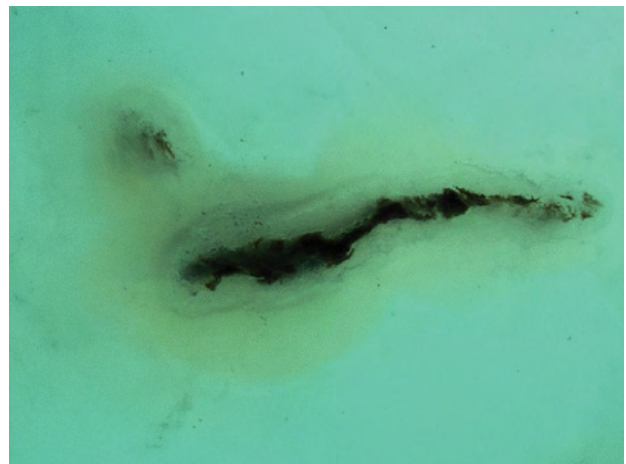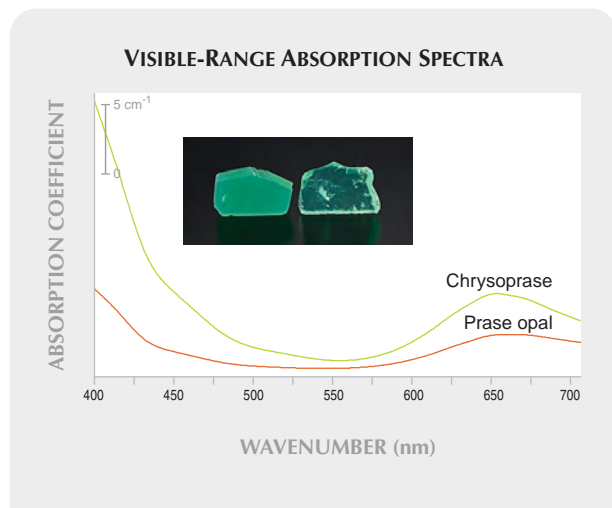
Figure 9. These visible-range spectra are for representative polished slabs of similar thickness of the chrysoprase (path length 1.86 mm) and prase opal (path length 1.76 mm). Both spectra exhibit regions of absorption below 500 nm and above 600 nm. The inset photo (by Robert Weldon) shows the similar color of both materials, as well as the greater transparency of the prase opal, on the right.

NEAR-IR ABSORPTION SPECTRA
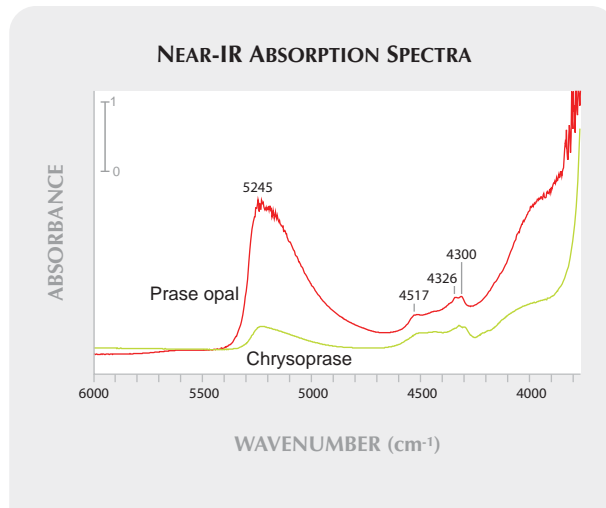
Figure 10. These representative infrared absorption spectra of the chrysoprase and prase opal display a band at ~5245 cm⁻¹ (more intense in the prase opal) and a group of similar features at 4517, 4326, and 4300 cm⁻¹.

groundmass. In contrast, they found that the silica spherules in the Tanzanian prase opal were an order of magnitude smaller (~5–6 μm). They described the chrysoprase as also containing "cloudy color distributions, clear chalcedony veinlets, whitish dots (microcavities), small fluid inclusions in bypyramidal quartz, and brownish inclusions of host rock" (p. 162) based on microscopic observations (10×–60× magnification and various lighting conditions). They interpreted the lack of a vapor phase in the liquid inclusions as implying that the chrysoprase formed at a very low temperature and was deposited by repeated evaporation of Si-rich hydrothermal solutions or surface waters along open fractures in the altered serpentinite host rock.

Chemical Analysis. Our EDXRF analyses indicated major amounts of Si and minor Ni, Zn, and Fe in both materials. Using atomic absorption spectroscopy, Kinnunen and Malisa (1990) measured 0.55 wt.% Ni in the chrysoprase, along with trace amounts of other elements (including the transition metals Co, Zn, Fe, Mn, and Cu at values up to 120 ppm, and rare-earth elements at 1 ppm or less).

Spectroscopy. The visible-range spectra of both materials showed increasing absorption below about

500 nm and a broad peak centered near 650 nm (figure 9), corresponding to the absorption patterns seen with the spectroscope (see also Schmetzer et al., 1976; Sachanbiński et al., 2001). This is consistent with the spectrum for chrysoprase from Tulare County, California (Rossman, 2009). The region of absorption above 650 nm has been attributed to Ni^{2+} in octahedral coordination in a silicate mineral (Rossman, 1994, pp. 458–459; there is no indication that this element substitutes for either silicon or oxygen in either the chrysoprase or the prase opal).

The near-infrared spectra were similar for both materials (figure 10), with a broad band at ~5245 cm⁻¹ and a group of features at 4517, 4326, and 4300 cm⁻¹ due to the presence of water molecules or hydroxyl groups in both materials (similar spectra for opals are illustrated in Langer and Flörke, 1974).

In contrast, the Raman spectra of the two materials were very different from one another (figure 11). In the chrysoprase, there were sharp Raman peaks at 1160, 807, 463 (much more intense than the other peaks), 398, 354, and 264 cm⁻¹. All of these features were reported previously in a study of the Raman spectra of microcrystalline silica (including chalcedony) by Kingma and Hemley (1994). The Raman spectra of the prase opal exhibited peaks at 783, 671, and a broader feature at 325 cm⁻¹. Similar features at ~800–780 and ~325 cm⁻¹ were reported in opals by Ostrooumov et al. (1999) and by Smallwood (2000).

RAMAN SPECTRA

INTENSITY →

Prase opal

463   325

783   671

Chrysoprase

1160   807   398   354   264

2000 1800 1600 1400 1200 1000 800 600 400 200

RAMAN SHIFT (cm⁻¹)
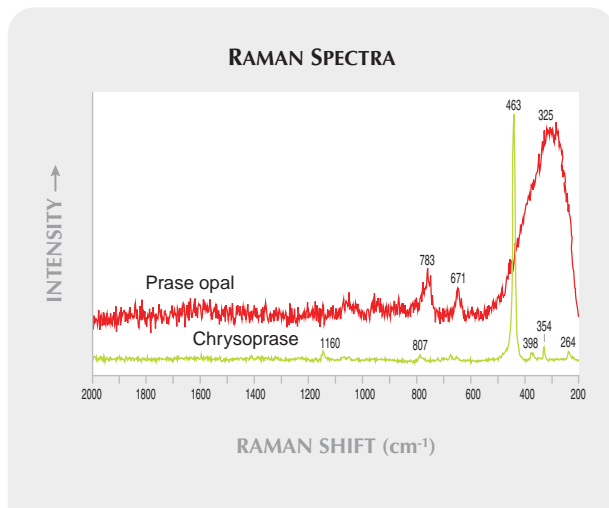
Figure 11. The Raman spectra for the chrysoprase and prase opal differ significantly.

CONCLUSION

Jewelry-quality chrysoprase and prase opal (figure 12) are mined from altered serpentinite near Haneti, Tanzania. The gemological properties of both materials are generally consistent with previous reports for chrysoprase and opal, and we did not find any features that distinguish them from the same materials from other localities. Chrysoprase can be separated from chrome chalcedony by the latter's yellow UV fluorescence, red Chelsea color filter reaction, and sharp absorption line at 684 nm seen with a spectroscope (Hyršl, 1999). Although similar in color and visual appearance, chrysoprase and prase opal from the Haneti area can be readily distinguished from one another on the basis of RI and SG values, as well as by their Raman spectra. Field observations of the mining site on Iyobo Mountain suggest good potential for future production.
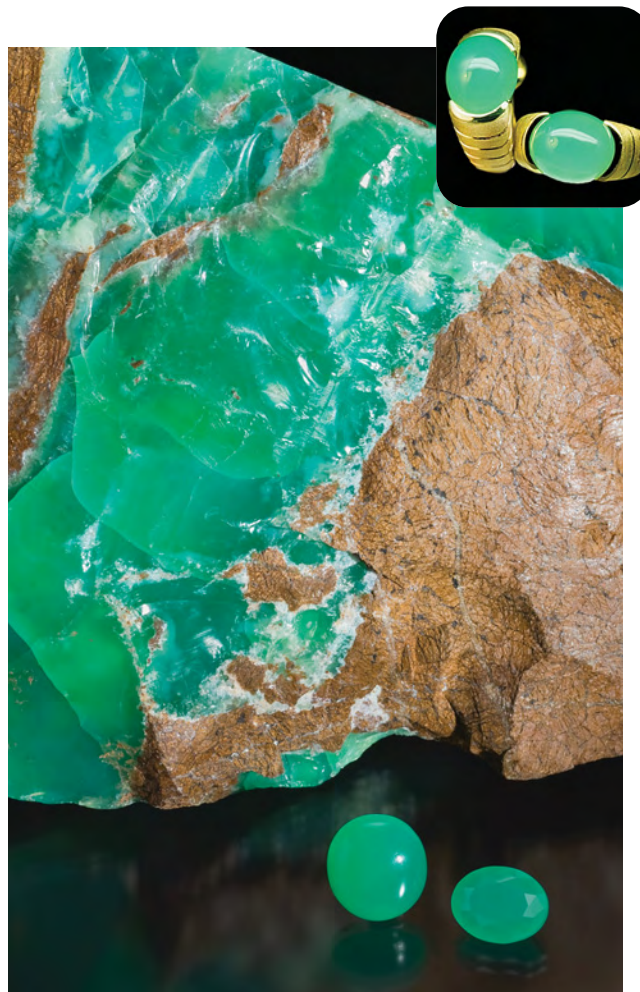
Figure 12. These Tanzanian prase opal samples consist of a 10.22 ct cabochon and a 5.15 ct faceted stone, together with a vein of rough material (GIA Collection nos. 32590, 32589, and 32587, respectively; photo by Robert Weldon). Tanzanian chrysoprase has been set into a variety of jewelry styles, as shown by the earrings in the inset (~9 ct total weight; courtesy of Dimitri Mantheakis).

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DEMANTOID FROM VAL MALENCO, ITALY: REVIEW AND UPDATE

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Loredana Prosperi, and Valentina Palanza

New data are presented for demantoid from Val Malenco, Italy, as obtained by classical gemological methods, electron microprobe and LA-ICP-MS chemical analyses, and UV-Vis-NIR and mid-IR spectroscopy. The results confirmed that these garnets are almost pure andradite (≥98 mol%, RI >1.81, SG = 3.81–3.88). All 18 samples studied contained "horsetail" inclusions, which are characteristic of a serpentinite geologic origin. Fe and Cr control the coloration of demantoid, though color variations in these samples were mainly correlated to Cr content.

Demantoid is the Cr-bearing yellowish green to green variety of andradite $[Ca_3Fe_2(SiO_4)_3]$ (O'Donoghue, 2006). Very popular in Russia (where it was first discovered) from about 1875 to the start of the Russian Revolution in 1917, this gem has enjoyed a resurgence in demand since the beginning of the 21st century (Furuya, 2007).

One of the most notable localities for demantoid is Val Malenco, located in Sondrio Province in the Lombardy region of northern Italy. Several deposits in this area have produced well-formed rhombic dodecahedral crystals (e.g., figure 1, left) that are coveted by collectors (Bedogné and Pagano, 1972; Amthauer et al., 1974; Bedogné et al., 1993, 1999). A

limited quantity (some thousands of carats) of Val Malenco demantoids have been cut, producing gemstones that are attractive but rarely exceed 2 or 3 ct (e.g., figure 1, right).

Val Malenco demantoid was first documented by Cossa (1880), who studied a sample recovered by T. Taramelli in 1876. In the next century, Sigismund (1948) and Quareni and De Pieri (1966) described the morphology and some physical and chemical properties of this garnet. Subsequently, the demantoid was investigated by Bedogné and Pagano (1972), Amthauer et al. (1974), Stockton and Manson (1983), and Bedogné et al. (1993, 1999). Because some of these data are more than 20 years old, and some publications are in Italian, we prepared this review and update on the physical, chemical, and gemological properties of demantoid from Val Malenco.

Note that *demantoid*—although commonly used as a trade or variety name—is not approved by the International Mineralogical Association as a mineral name (Nickel and Mandarino, 1987; O'Donoghue, 2006). However, for reasons of brevity and consistent with gemological convention, throughout this article we will use *demantoid* instead of *andradite, variety demantoid*.

HISTORY AND PRODUCTION

Most of the demantoid recovered from Val Malenco thus far has been found in asbestos mines located in a small area between Dossi di Franscia and Coston d'Acquanegra (figure 2). The most famous localities are: Cengiàsc (including the Sferlùn quarry), Dossi di Franscia, Coston d'Acquanegra, Valbrutta, and Al Ross (Bedogné et al., 1999). These asbestos deposits are located at ~1800–2200 m above sea level, and are not easily accessible.

Probably the most beautiful Italian demantoid

Figure 1. The demantoid crystal (9.01 × 9.42 mm) and 1.98 ct faceted cushion cut are from the Sferlùn mine in Val Malenco, Italy. Left image courtesy of the Museo di Storia Naturale di Milano, Italy, and Dr. Federico Pezzotta; photo by Matteo Chinellato. Right image courtesy of Francesco Bedogné; photo by Roberto Appiani.

crystals were found at the Sferlùn mine by L. Magistretti in 1947 (Sigismund, 1948). Some were given to Università degli Studi di Milano, while others were sold to jewelers and collectors. Other important finds were made during the second half of the 1960s (Bedogné et al., 1999).

At present, all the asbestos mines are closed, so the possibility of collecting fine demantoid specimens is very remote. The existing demantoid crystals and cut stones on the market came from commercial exploitation before the mines closed toward the end of the 1970s (Bedogné et al., 1999).

GEOLOGIC SETTING

The Val Malenco ultramafic rocks (again, see figure 2) mainly consist of magnetite-, diopside-, and antigorite-bearing serpentinites that formed by metamorphism of mantle rocks during the Alpine orogenesis (Montrasio et al., 2005; Trommsdorff et al., 2005). The demantoid is found within foliated serpentinites in the eastern part of the Val Malenco ultramafic unit, where it is hosted by asbestos (chrysotile)–filled brittle fractures, generally oriented perpendicular to the foliation. The demantoid may be found as crystals up to 2 cm in diameter (see figures 1 [left] and 3), or as aggregates of tiny crystals that are locally dubbed "asbestos seed."

The demantoid crystals are generally associated with magnetite, Cr-bearing magnetite, calcite, hydromagnesite, brucite, clinochlore, and rarely, transparent green masses of forsterite. This assemblage has hydrothermal origins and formed in a retrograde metamorphic process during the late Alpine orogenesis at temperatures below 370°C and pressures ranging from 0.5 to 1.5 kbar (Amthauer et al., 1974).

MATERIALS AND METHODS

We examined 18 samples from Val Malenco consisting of eight faceted (0.31–3.84 ct; see, e.g., figure 4)

and 10 rough (0.01–0.4 g) specimens taken from 10 different rock samples, the latter all from the Sferlùn mine. All the faceted samples were examined by standard gemological methods to determine their optical properties, hydrostatic specific gravity, UV fluorescence, and microscopic features.

Quantitative chemical analyses were performed on eight of the rough samples, selected on the basis of color (representing a range from yellowish green to green to intense green). We used a JEOL JXA-8200 electron microprobe in wavelength-dispersive mode. The following elements were measured: Na, Mg, Al, Si, K, Ca, Ti, V, Cr, Mn, and Fe. We corrected the raw data for matrix effects using a conventional ZAF routine. The oxidation state of Fe was determined for all the samples, using the flank method, which allows one to directly determine the ferric iron content from microprobe data (Höfer and Brey, 2007).

Laser ablation–inductively coupled plasma–mass spectroscopy (LA-ICP-MS) chemical analyses were performed on the same samples analyzed by electron microprobe. The instrument consisted of an Elan DRC-e mass spectrometer coupled with a Q-switched Nd:YAG laser source, with a fundamental emission (1064 nm) that was converted to 266 nm by two harmonic generators. Helium was used as a carrier gas, mixed with an Ar stream in the ablation cell. The following elements were analyzed: Li, Be, B, Sc, Ti, V, Cr, Co, Ni, Zn, Rb, Sr, and the rare-earth elements from La to Lu.

Ultraviolet-visible–near infrared (UV-Vis-NIR) spectroscopic measurements over the 250–1000 nm range were performed with a Lambda 950 PerkinElmer spectrophotometer, equipped with an integrating sphere, on four rough samples (nos. 1, 2, 6, and 8, having thicknesses of 1.90, 2.04, 1.82, and 1.40 mm, respectively).

Spectroscopic measurements of all the rough samples over the mid-infrared range (4000–400 cm^{-1}) were performed with a Nicolet Nexus Fourier-transform infrared (FTIR) spectrometer, operating in dif-

Figure 2. Demantoid is hosted by serpentinites in the eastern part of the Val Malenco ultramafic unit, northern Italy. The presence of "horsetail" inclusions in the garnet is consistent with the serpentinite origin.
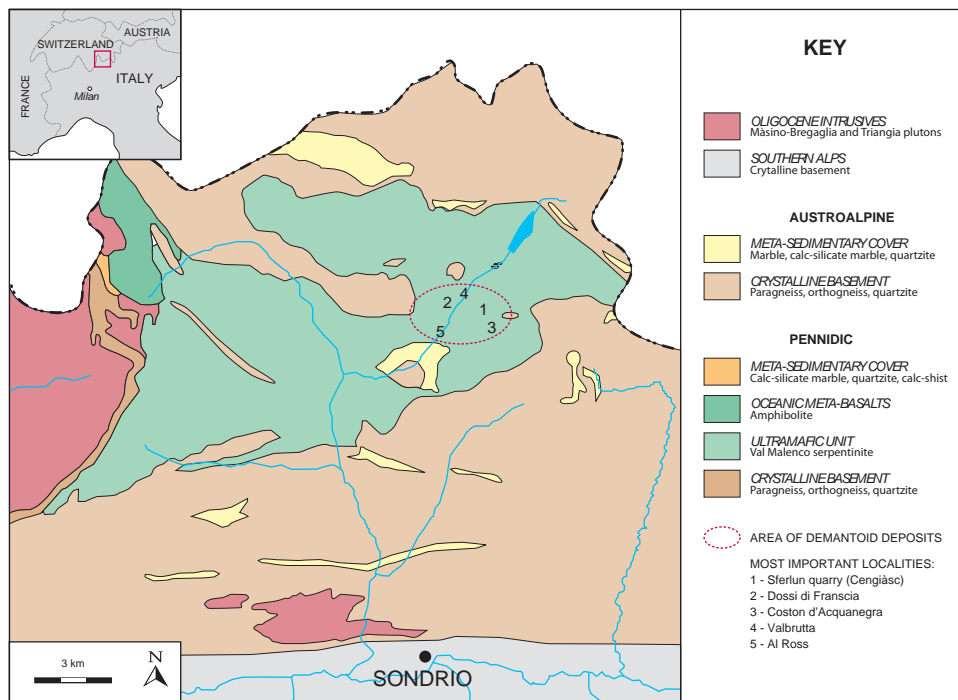
fuse reflectance (DRIFT) mode, with a resolution of 4 cm^{-1} and 200 scans per sample. Three crystals were also tested in transmission mode using the same operating conditions.

Figure 3. A group of well-formed demantoid crystals are associated with asbestos on a serpentine matrix in this sample from the Sferlùn mine. The largest crystal is ~20 mm across. Courtesy of the Earth Sciences Department Museum of the Università degli Studi di Milano, Italy (Magistretti Collection); photo by R. Bocchio.

RESULTS AND DISCUSSION

Standard Gemological Properties. The color of both the rough and faceted samples ranged from yellowish green to green, including a rare bright intense "emerald" green (seen in six samples, especially the smallest ones), with a medium-to-dark tone. The color was generally homogeneous, but one rough sample (no. 10) contained inclusions near the core that darkened the overall appearance. All the crystals studied had dodecahedral habits, often modified by trapezohedron faces that were finely striated lengthwise.

The standard gemological properties, summarized in table 1, are typical of andradite (O'Donoghue, 2006). The properties are also comparable to those obtained by Stockton and Manson (1983) on seven samples of demantoid reportedly from Italy.

All of our samples contained fibrous inclusions, identified as chrysotile on the basis of morphology, in the typical "horsetail" arrangement (figure 5). One stone had been cut with these fibers placed under the table facet to emphasize their distinctive beauty. "Horsetail" inclusions have been previously documented in samples from Val Malenco (e.g., Hoskin et al., 2003; Gübelin and Koivula, 2005), and such internal features are typical of demantoid hosted by serpentinite. The faceted samples also contained many fractures, some healed with liquid or solid materials. Straight growth lines were observed in one stone, and two samples contained white

inclusions of what was probably a serpentine-group mineral (e.g., antigorite; see figure 5, left), as documented by Gübelin and Koivula (2005) in demantoid from this locality.

Chemical Composition. The chemical compositions of the eight analyzed samples from Val Malenco are summarized in table 2.

<div style="border:1px solid green; padding:10px;">

NEED TO KNOW

• Demantoid is a variety name for Cr-bearing yellowish green to green andradite.

• Demantoid from Val Malenco has been known since the late 19th century, but only limited amounts have been cut.

• Val Malenco demantoid is almost pure andradite, and contains "horsetail" inclusions.

• The intensity of the green coloration correlates to Cr content, which was measured in relatively low concentrations (up to ~5500 ppm).

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Electron microprobe analyses showed that all the garnets consisted of nearly pure andradite (≥98 mol%), and that Ti, V, Al, Cr, Mn, Mg, Na, and K were present only in amounts of <1 wt.% oxide, which is consistent with data previously reported by Amthauer et al. (1974), Stockton and Manson (1983), and Bedogné et al. (1999). Chromium was the most important chromophore other than iron, with average values ranging up to 0.58 wt.% Cr_2O_3. Moreover, this element was heterogeneously distributed within each sample (see, e.g., figure 6). Amthauer et al. (1974) also measured variable Cr_2O_3 contents in different colors of demantoid from Val Malenco (i.e., 0.02–1.30 wt.%; the highest contents were measured in intense green samples). Bedogné et al. (1999) reported a strong Cr_2O_3 variation (from traces up to 2.48 wt.%) between different samples. Stockton and Manson (1983) reported small amounts of Cr_2O_3 (approaching the detection limit of the microprobe) in almost all the yellowish green samples investigated from this locality, noting also a heterogeneous composition, especially with regard to chromium.

LA-ICP-MS analyses measured significant values (more than a few parts per million) of only three elements: Cr, Ti, and V (table 2). Ti and V were rather constant, and did not show any correlation with color; Cr, however, was quite variable and did correlate to the intensity of green coloration (figure 7). In

Figure 4. These faceted demantoids from Val Malenco (0.31–0.91 ct) are some of the cut samples tested for this study. Photo by Matteo Chinellato.

the yellowish green specimens (nos. 1–3), Cr contents were below or very close to the detection limit of the microprobe, with levels ranging up to 250 ppm measured by LA-ICP-MS. The greener stones (nos. 4–8) contained higher Cr contents, up to ~5500 ppm. The variation of Cr within a single sample (again, see figure 6) was also evident in the LA-ICP-MS data (see ranges in table 2). The content and distribution of the rare-earth elements, as measured by LA-ICP-MS, will be discussed in a separate article.

Chemical analysis of the dark inclusions in sample no. 10 (figure 8) identified them as Cr-bearing magnetite, with 16.63–23.08 wt.% Cr_2O_3. Magnetite and Cr-bearing magnetite are common in demantoid associated with serpentinite, and were observed by Bedogné and Pagano (1972) as small grains in

TABLE 1. Gemological and spectroscopic properties of andradite/demantoid from Val Malenco, Italy, investigated in this study.

Color	Yellowish green to green, medium to dark
Diaphaneity	Transparent
Optic character	Singly refractive with moderate-to-strong anomalous double refraction
Refractive index	>1.81
Specific gravity	3.81–3.88
UV fluorescence	Inert
Internal features	"Horsetail" inclusions, crystalline inclusions (probably belonging to the serpentine mineral group), fractures (some partially healed), straight growth lines
UV-Vis-NIR spectroscopy	Total absorption below 390 nm, strong bands at 435–440 nm, broad feature at 480 nm, absorptions at 575, 620, 640 nm, a doublet at 695–700 nm, and a broad band at 860 nm
Mid-IR spectroscopy	Areas of total absorption between 2250 and 400 cm^{-1} intrinsic to garnet; bands at 3560 and 3604 cm^{-1} related to structurally bonded OH^{-}

TABLE 2. Chemical composition of eight andradites from Val Malenco, Italy.

Chemical composition	No. 1 Yellowish green	No. 2 Yellowish green	No. 3 Yellowish green	No. 4 Green	No. 5 Green	No. 6 Green	No. 7 Green	No. 8 Green
Electron microprobe analyses (average)[a]								
No. points analyzed	11	10	7	11	11	10	10	10
Oxides (wt.%)								
SiO_2	35.95	35.39	35.37	35.93	35.76	35.73	35.88	35.81
TiO_2	0.02	0.03	0.01	0.01	0.04	0.05	0.03	0.02
Al_2O_3	0.06	0.08	0.07	0.15	0.06	0.08	0.06	0.05
Cr_2O_3	bdl	0.01	0.03	0.18	0.19	0.29	0.47	0.58
Fe_2O_3[b]	31.60	31.51	31.60	31.05	31.27	30.98	31.07	31.01
MnO	0.01	0.03	0.03	0.02	0.02	0.03	0.02	0.04
MgO	0.10	0.12	0.13	0.15	0.13	0.17	0.09	0.11
CaO	33.04	33.04	33.04	33.06	33.02	32.98	32.99	33.04
Na_2O	0.01	0.01	0.01	0.01	bdl	bdl	bdl	bdl
Total	100.79	100.22	100.29	100.56	100.49	100.31	100.61	100.66
Ions per 12 oxygens								
Si	3.011	2.987	2.985	3.014	3.005	3.007	3.010	3.004
Ti	0.001	0.002	0.001	0.001	0.003	0.003	0.002	0.001
Al	0.006	0.008	0.007	0.015	0.006	0.008	0.006	0.006
Cr	bdl	0.001	0.002	0.012	0.013	0.019	0.031	0.039
Fe^{3+}	1.992	2.001	2.006	1.960	1.977	1.962	1.961	1.958
Mn	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.003
Mg	0.012	0.015	0.016	0.019	0.016	0.021	0.011	0.014
Ca	2.965	2.988	2.987	2.971	2.975	2.974	2.965	2.970
Na	0.001	0.002	0.002	0.002	bdl	bdl	bdl	bdl
Mol% end members								
Andradite	99.6	99.9	99.9	98.7	99.2	98.6	98.8	98.3
Uvarovite	0.0	0.0	0.0	0.6	0.2	1.0	0.8	1.1
Others	0.4	0.1	0.1	0.7	0.6	0.4	0.4	0.6
LA-ICP-MS analyses[c]								
No. points analyzed	3	6	6	3	4	3	3	3
Element (ppm)								
Cr	6–23 (12)	2–188 (67)	11–250 (113)	16–5089 (682)	1621–3302 (2553)	1028–1467 (1271)	690–5468 (2568)	3899–4480 (4189)
Ti	113–233 (180)	78–649 (266)	110–152 (126)	7–157 (89)	157–292 (228)	156–458 (300)	67–195 (120)	68–87 (60)
V	35–41 (37)	33–86 (52)	26–28 (28)	12–43 (35)	52–70 (62)	51–69 (57)	65–91 (74)	39–46 (43)

[a] Electron microprobe operating conditions: accelerating voltage = 15 kV, beam current = 15 nA, count time = 60 seconds on peaks and 30 seconds on background. Standards: natural wollastonite (Si, Ca), anorthite (Al), fayalite (Fe), olivine (Mg), rhodonite (Mn), omphacite (Na), ilmenite (Ti), K-feldspar (K), and pure V and Cr for those elements. Abbreviation: bdl = below detection limit (0.01 wt.%). Potassium and vanadium were below the detection limit in all analyses.

[b] Total iron calculated as Fe_2O_3. The flank method established that all iron is Fe^{3+}.

[c] LA-ICP-MS operating conditions: spot size = 40 μm; external standard = NIST SRM 610 glass; internal standard = Ca. Precision and accuracy estimated on the basaltic glass BCR2 standard were better than 10%. Data include ranges, with average values in parentheses. Several other elements (see text) were present at no more than a few ppm, and are not included here.

samples from Val Malenco. In sample no. 10, enriched amounts of Cr (and relatively low Fe) were also present in the garnet adjacent to these inclusions (figure 8). The Cr_2O_3 content varied from 10.09 to 3.78 wt.% with increasing distance from the Cr-bearing magnetite grain.

Spectroscopy. The most significant spectroscopic features in the investigated samples are summarized in table 1 and described below.

UV-Vis-NIR. As illustrated by the two representative samples in figure 9, the UV-Vis-NIR absorption spectra are characterized by total absorption below 390 nm, an intense peak at ~440 nm with a second component at ~435 nm, two bands at 575 and 620

Figure 5. All the Val Malenco samples investigated for this study contained fine fibers of chrysotile in a "horsetail" arrangement, as is typical of demantoids occurring in serpentinite. The white masses in the left photo were identified as a serpentine mineral such as antigorite. Photomicrographs by Vanda Rolandi; magnified 45×.
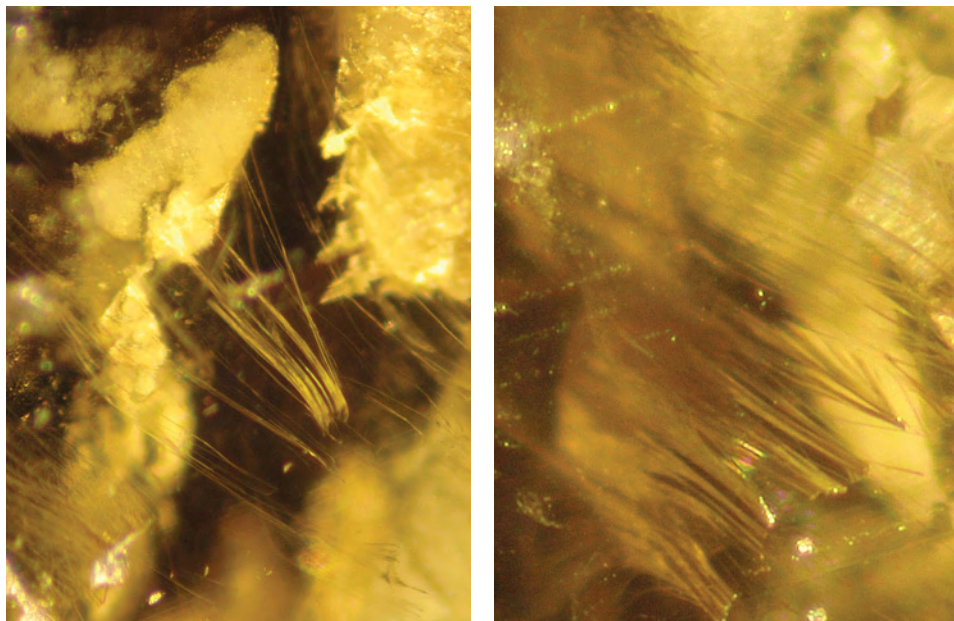
nm that sometimes overlap, and a broad band at ~860 nm. These spectral features are all related to Fe^{3+} and Cr^{3+}. In particular, the features at 390, 440, 575, and 860 nm are related to Fe^{3+}. The 440 nm band is also attributed to Cr^{3+}, as is a feature at ~480 nm; both of these were seen to increase proportionally to chromium content in spectra taken from slabs of the same thickness. The 620 nm band is also assigned to Cr^{3+}, though we cannot exclude a weak

contribution from Fe^{3+} (for all these assignments see, e.g., Manning, 1972; Moore and White, 1972; Amthauer et al., 1974; Amthauer, 1976). Absorption in the 500–700 nm range could be a rough indicator of Cr content in demantoid, although this correlation is in need of proper calibration. In samples with very low Cr (e.g., no. 2, with 67 ppm Cr average), the 575 nm band was clearly evident, whereas the 620 nm feature was only suggested. However, the 575

Figure 6. This X-ray map obtained with the electron microprobe shows the Cr distribution in sample no. 7.
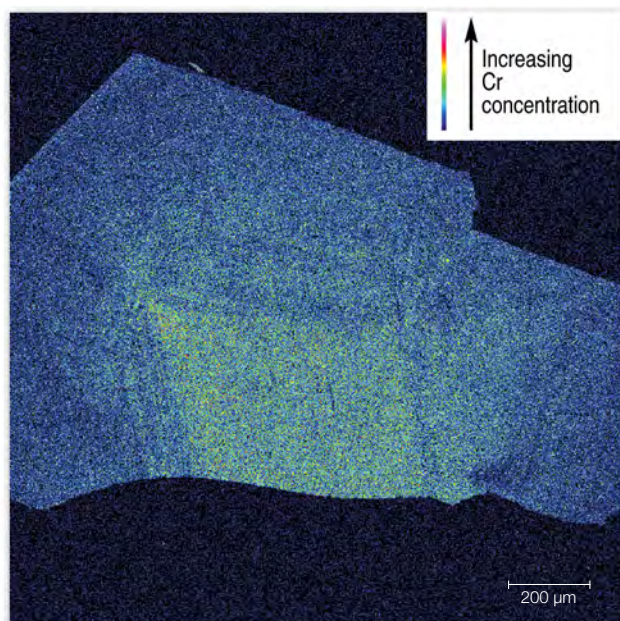
Figure 7. The average contents of Cr, V, and Ti obtained by LA-ICP-MS are shown for eight rough andradite/demantoid samples investigated for this study, according to the intensity of their color (see table 2 for data).
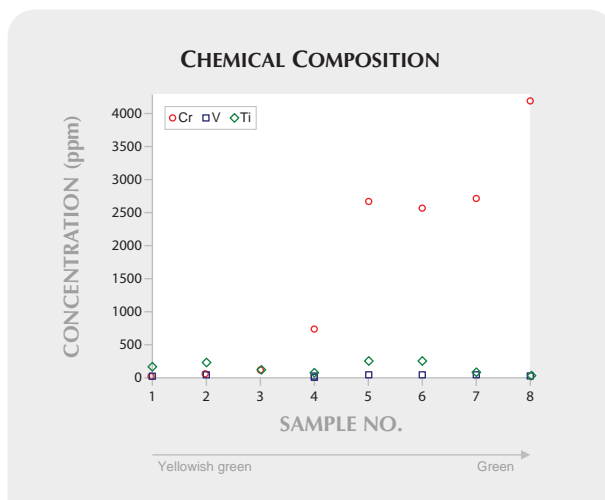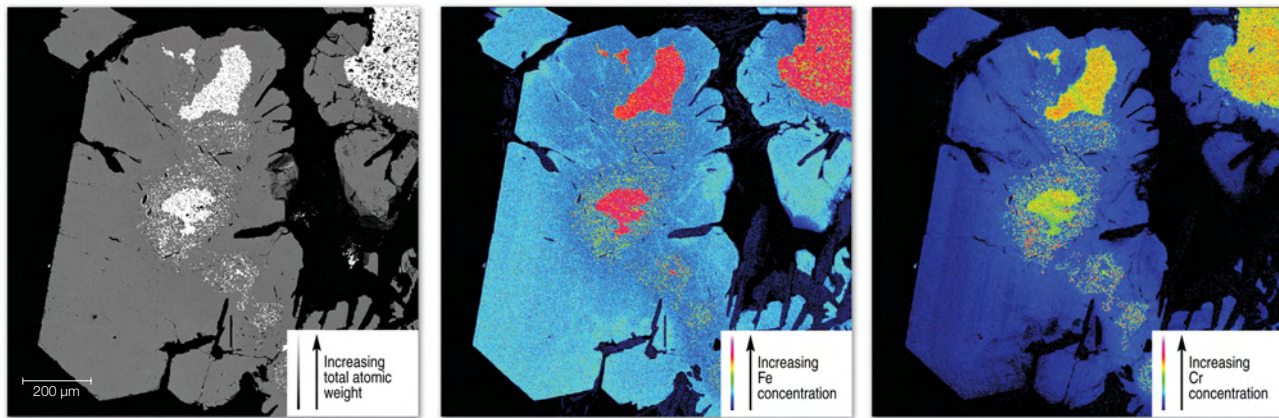
Figure 8. The white areas in the backscattered electron image on the left are inclusions of Cr-bearing magnetite in sample no. 10. The X-ray maps (center and right) show the distribution of Fe and Cr in the inclusions and the host garnet.

nm band was obscured in the Cr-abundant samples by the more intense 620 nm feature. A 695–700 nm doublet and a weak peak at 640 nm, both related to Cr^{3+} (Burns, 1993; O'Donoghue, 2006), were also seen—though with difficulty—in specimens with a higher Cr content (e.g., no. 6).

Mid-Infrared. The mid-IR spectra of all the rough samples—both in diffuse reflectance and transmission modes—showed areas of total absorption in the 2250–400 cm^{-1} range, intrinsic to garnet, along with one or more bands between 3650 and 3450 cm^{-1} (figure 10). The dominant absorption peak at ~3560 cm^{-1} and the weaker absorption at 3604 cm^{-1} are related to hydroxide, which can be present in andradite as a minor component, in the form of structurally bonded OH^{-} (Amthauer and Rossman, 1998).

CONCLUSION

Demantoid from Val Malenco is an attractive gem material that consists of almost pure andradite ($\geq$ 98 mol%) and has typical gemological properties for this garnet variety. "Horsetail" inclusions are common and are consistent with the demantoid's geologic origin related to serpentinite. Infrared spectroscopy showed that hydroxide is a minor component of this garnet.

The color, ranging from yellowish green to green, is due to intrinsic iron and traces of chromium, as shown by chemical analyses and UV-Vis-NIR spectroscopy. In particular, Cr^{3+} causes the purer green coloration, despite the often low amounts present. Mining at Val Malenco is no longer active, but thousands of carats of faceted demantoid from this area have entered the market over the years.

Figure 10 The mid-IR spectrum in transmission mode of Val Malenco demantoid (here, sample no. 4, 1.50 mm thick) shows absorption features related to OH^{-} at 3604 and 3562 cm^{-1}.

Figure 9. UV-Vis-NIR spectra are shown here for two representative samples from Val Malenco: no. 2 (average Cr = 67 ppm) and no. 6 (average Cr = 1271 ppm).

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A New CHALCEDONY Treatment

A while ago we learned of a new type of chalcedony on the market. Most of the material had the bodycolor of carnelian, but it was marked by an unusual network of white lines of varying degrees of prominence. There was an abundance of this chalcedony at the Tucson gem shows, so the Carlsbad laboratory acquired two strands of beads for testing (figure 1).

The beads were identified as chalcedony based on their RI of 1.53, aggregate structure, and the typical agate banding underlying the network of white lines in many of them. Magnification showed that the white lines followed fractures in a pattern typical of that caused by quench crackling (figure 2). The white coloration penetrated the body of the stones a very short distance on either side of the fractures and part of the way down toward the center of the stones.

We are not aware of any report of the natural formation of such cracks in chalcedony, so to investigate further we cut several beads in half (e.g., figure 3). It immediately became clear that the fractures did not extend all

Figure 1. These two strands of treated chalcedony were acquired for testing; the network of white lines is much more distinct in the top strand. The round beads are ~12.0 mm in diameter.

the way through the beads but penetrated a roughly uniform distance from the surface. This depth varied from bead to bead, being deeper in those with more-prominent white lines. The white zones followed the fractures precisely and ended where they stopped (again, see figure 3). One bead also had a narrow white layer along its surface.

This arrangement is clearly not natural. We do not know the exact treatment, but it appears to be a combination of quench crackling followed by some type of bleaching process.

Although this is just one of many chalcedony treatments, we recently learned that this material is being represented as fire agate—a brown chalcedony that displays multicolored iridescence and commands a higher price than most other chalcedonies.

The beads we examined bear no resemblance to fire agate, and it is misleading to refer to them as such.

Since acquiring the initial samples, we have seen this treated chalcedony in several unnatural dyed colors, most notably green, blue, and pink. Indeed, some dealers have told us that even the carnelian color is the result of dyeing.

An Internet search readily revealed an abundance of this merchandise. One popular auction site showed hundreds of results with many variations on the name, such as "Crab Fire Agate," "Fire Dragon Veins Agate," and "Crackle Fire Agate." Most disturbing, however, were several entries in which the material was labeled natural fire agate—a clear misrepresentation of this treated chalcedony.

Shane McClure

Figure 2. Magnification revealed that the white lines followed fractures in a pattern typical of quench crackling. Field of view ~5.3 mm high.

DIAMOND

DiamondView Indicates Treatment in Irradiated Brown-Orange Diamond

The Diamond Trading Company (DTC) DiamondView instrument is a valuable tool for observing variations in fluorescence patterns that correlate to a diamond's growth history, and is therefore useful for differentiating natural from synthetic diamonds. The fluorescence seen with the DiamondView generally shows no correlation with the facets of cut diamonds. Recently, however, we examined a diamond at the New York laboratory that showed strikingly different Diamond-View fluorescence features between the table and pavilion facets.

The 1.49 ct pear-shaped brilliant was graded Fancy Deep brown-orange. The stone's bodycolor appeared evenly distributed when viewed face-up with the unaided eye (figure 4). However, microscopic examination revealed that the apparent color was concentrated in the crown and penetrated only a shallow distance into the stone, with a sharp boundary that followed the girdle facets (figure 5). Such facet-associated color zoning is common in diamonds that have been irradiated to artificially change or induce their color. When observed through the

Figure 3. These two chalcedony beads were cut in half. Note that the fractures in the oval bead, where the white lines are more distinct, are significantly deeper and the white zones terminate with the fractures. The round bead is ~12.0 mm in diameter.

pavilion, the bodycolor appeared lighter than was seen face-up.

Infrared (IR) absorption spectroscopy revealed that the diamond was type IaB with a moderate-to-high concentration of nitrogen. Banded brown graining was present, as is typical of type IaB brown diamonds. The stone showed moderate green transmission luminescence when examined with a fiber-optic light, and it fluoresced a chalky green that followed the graining when exposed to long-

Figure 4. This 1.49 ct diamond owes its Fancy Deep brown-orange color to laboratory irradiation.

and short-wave ultraviolet (UV) radiation. UV-visible absorption spectroscopy showed a strong absorption at 595 nm, which—along with the color zoning—indicated that this diamond had been artificially irradiated.

In the DiamondView, the pavilion fluoresced a strong blue (created by the N3 defect, at 415 nm), while the crown facets fluoresced a strong green-yellow (figure 6); these contrasting areas were separated by a clear, sharp boundary. The green-yellow fluorescence is attributed to the H3 defect (503.2 nm), which was observed in photoluminescence spectra taken from the table facet using 488 nm excitation at liquid-nitrogen temperature.

The combined gemological and spectroscopic features recorded for this diamond strongly indicated that it had been irradiated and annealed, with the table and crown facets facing the high-energy beam. After annealing at relatively low temperatures, the table/crown facets had a very different defect configuration than the pavilion region, since the high-energy beam had only a limited penetration depth. The areas of contrasting defects were clearly seen with the DiamondView, demonstrating the power of this instrument for quickly helping identify such laboratory-treated diamonds.

Stones showing strong contrasts or unusual fluorescence patterns in the DiamondView should be subject-

Figure 5. The diamond's color was concentrated in a shallow zone following the girdle facets. Magnified 22×.

Figure 6. This DiamondView image shows a clear distinction between the table/girdle facets (yellow-green, H3 defect) and the pavilion facets (blue, N3 defect).

The diamond fluoresced weak yellow to long-wave UV radiation and very weak yellow to short-wave UV. With a desk-model spectroscope, we observed absorption bands at 415 (N3), 478 (N2), and 503.2 (H3) nm. We did not see the H-related absorption bands at 545 and 563 nm, but IR spectroscopy revealed strong H-related peaks at 3107 and 1405 cm^{-1}. The presence of hydrogen peaks in the IR region but not the UV-Vis region indicated that hydrogen occurred mainly in infrared-active forms.

The crystallographic relationship of the flower-shaped cloud to the orientation of the octahedral form makes this diamond unique. The cutter capitalized on this striking natural form.

Jason Darley, Erica Emerson, and Paul Johnson

Unusual Trigon-Shaped Clouds Indicate Two Diamonds Cut from the Same Piece of Rough

Clouds composed of submicroscopic inclusions in diamond usually follow the cubic growth sector [100], and as with the previous entry, attractive symmetrical patterns are occasionally seen. Some clouds, though, impart interesting information about the origin of the stone.

The New York laboratory recently received two square modified brilliants, 1.18 and 1.24 ct, for identification and grading services. When we viewed the Fancy yellow diamonds through their pavilions with a gemological microscope, we were surprised to see both had similar triangular cloud inclusions (e.g., figure 8), which were arranged in a triangular plane.

Trigon-shaped clouds are rare, so it was particularly interesting to see them in two diamonds and to note that the clouds occurred only in one side of each stone. The relationship these clouds implied was further supported by IR spectroscopy, which showed that the diamonds had identical nitrogen- and hydrogen-related absorptions. The mirror-image fluorescence patterns seen with the

Figure 7. This polished 10.01 ct octahedral diamond contains a flower-shaped cloud with six symmetrical petals.

DiamondView (figure 9) confirmed that these two diamonds were cut from the same piece of rough.

Isolated triangular cloud inclusions of this type are seldom seen. The Spring 1995 Lab Notes section (p. 53) reported on triangular inclusions that formed a plane associated with the diamond's octahedral face. In the two Fancy yellow diamonds described here, the triangular clouds were present along one of the octahedral growth sectors, and may represent trigons that were subsequently overgrown during further crystallization of the diamond.

Sally Chan

Figure 8. Viewed through the pavilion, this Fancy yellow diamond displayed clouds with rarely seen trigon shapes. Magnified 32×.

ed to further testing to investigate whether they may have been treated.

Sally Chan and Paul Johnson

Diamond with Flower-Shaped Cloud

Hydrogen is a common impurity in diamond, usually associated with clouds of submicroscopic inclusions. (In high concentrations, hydrogen can also contribute to brown or green hues.) While these hydrogen clouds are not uncommon, they rarely have a symmetrical pattern. When they do, skilled diamond cutters can take advantage of such striking inclusions (e.g., Summer 1976 G&G, p. 181).

The 10.01 ct (10.92 × 10.88 × 14.12 mm) octahedral diamond in figure 7 was submitted to the New York laboratory for a colored diamond identification and origin report. The stone had been polished to display a flower-shaped cloud with six symmetrical petals, three radiating upward and three downward. This symmetry suggested that the cloud followed the {100*} crystallographic direction—the only direction in which diamond has three-fold symmetry (W. Wang and W. Mayerson, "Symmetrical clouds in diamond—the hydrogen connection," *Journal of Gemmology*, Vol. 28, No. 3, 2002, pp. 143–152).

*Corrected 4/26/10

Fancy Intense Blue Type IIb SYNTHETIC DIAMOND

Type IIb blue diamonds with good color and clarity are among the most desirable of all gems. The New York laboratory recently received a 1.53 ct blue round brilliant (figure 10) for a grading report. Color graded Fancy Intense blue, the diamond was visually clean, free from the inclusions that are typical of type IIb natural diamonds. We did not observe any graining or internal strain patterns (also often seen in natural type IIb diamonds) when the stone was examined between crossed polarizers. A minor fracture was present, and with magnification we saw patchy blue zones in the pavilion (figure 10, right), which we have not commonly observed in natural or synthetic blue diamonds. Routine testing with IR spectroscopy confirmed the sample was type IIb with a relatively high boron concentration; as expected, it was electrically conductive.

The sample fluoresced weak orange to long-wave UV radiation and strong yellow-green to short-wave UV, with long-lasting (more than 30 seconds) blue-green phosphorescence after short-wave UV excitation. Most natural type IIb diamonds do not fluoresce to short-wave UV. The DiamondView images exhibited four-fold growth sectors (see arrows in figure 11) a feature that is typical of high-pressure, high-temperature (HPHT) synthesis (J. E. Shigley et al., "An updated chart on the characteristics of HPHT-grown synthetic diamonds," Winter 2004 *G&G*, pp. 303–313).

Natural type IIb diamonds are known to exhibit blue and especially red phosphorescence (S. Eaton-Magaña et al., "Using phosphorescence as a fingerprint for the Hope and other blue diamonds," *Geology*, Vol. 36, No. 1, 2008, pp. 83–86). Phosphorescence spectroscopy performed with a custom-built system equipped with an Ocean Optics spectrometer (USB4000) and a broadband Avantes deuterium light source (AvaLight DHS with a broadband range of
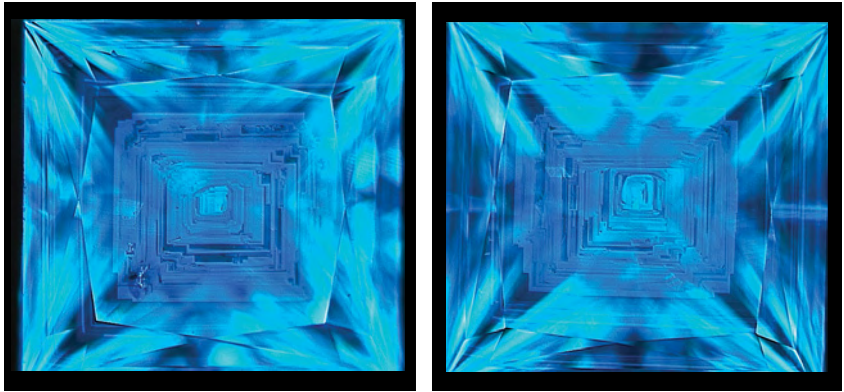
Figure 9. DiamondView fluorescence images of the two diamonds (1.18 and 1.24 ct) proved that they were faceted from the same piece of rough.

200–400 nm) revealed intense blue phosphorescence, centered at 500 nm, with a slow decay (calculated half-life of 7.0 seconds). However, no red phosphorescence was observed, consistent with a synthetic origin (again, see Eaton-Magaña et al., 2008). Time-dependent phosphorescence spectra are shown in figure 12.

Gem-quality HPHT-grown synthetic diamonds have improved significantly since GE first produced them experimentally in the early 1970s, and this sample was among the highest-quality blue synthetic diamonds of this relatively large size that GIA has examined to date. Nevertheless, gemological observation, Diamond-View imaging, and spectroscopic test-ing can still unambiguously identify HPHT-grown synthetics.

Ren Lu and Sally Eaton-Magaña

Colorless Cat's-Eye PHENAKITE

The beryllium silicate phenakite is commonly known to gemologists as an inclusion in synthetic emerald, though it has been described in association with natural Be-containing gems such as emerald and chryso-beryl (e.g., Fall 2003 GNI, pp. 226–227). Indeed, transparent phenakite has been found in localities such as Brazil and Sri Lanka, but such specimens are generally considered collectors' curiosities and are rarely

Figure 10. This 1.53 ct Fancy Intense blue round brilliant was found to be a type IIb HPHT-grown synthetic diamond. Patchy color zones and a frac-ture can be observed in the pavilion (right).
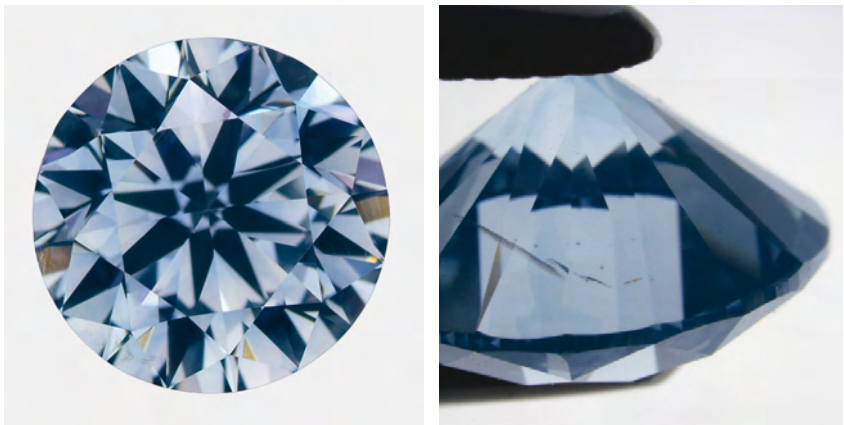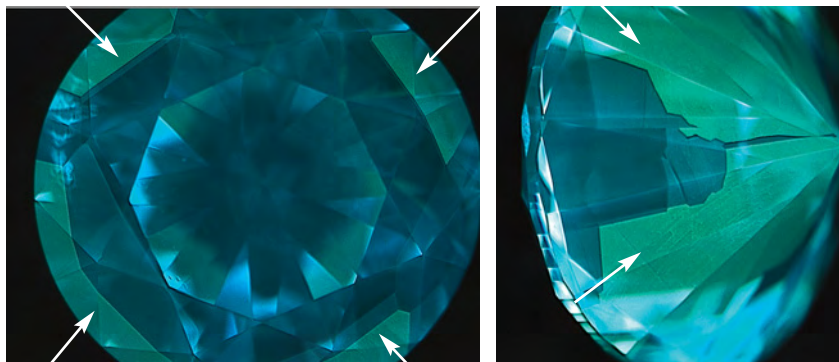
Figure 11. DiamondView fluorescence images showed the four-fold growth sectors (see arrows) typical of HPHT-grown synthetic diamonds.

encountered as fashioned gems.

We recently had the opportunity to examine a large colorless cabochon, represented as phenakite and said to be from Sri Lanka, that was loaned by Elaine Rohrbach of GemFare in Pittstown, New Jersey. The 38.34 ct gem (~18.19 × 17.77 × 14.81 mm) was transparent to the unaided eye, yet showed relatively strong chatoyancy extending across the dome (figure 13) when illuminated from above with a single light source. Gem-quality Sri Lankan phenakite is known to contain "needle-like" inclusions, which in sufficient quantity could produce chatoyancy.

The gemological properties (spot RI = 1.66, hydrostatic SG = 2.96, inert to long- and short-wave UV, and no visible-light absorption spectrum) were consistent with phenakite, and Raman analysis confirmed the identification. Examination with magnification and fiber-optic illumination revealed the expected cause of the chatoyancy: light reflections off numerous minute acicular tubes and platy voids (figure 14, left). These inclusions were aligned parallel to the optic axis, which was oriented in a plane parallel to the cabochon's base and perpendicular to the chatoyant band. Viewed with higher magnification, some of the iridescent platy voids displayed complex multicomponent interiors with the various components marked by sharply contrasting iridescent colors (figure 14, right). Since they were clearly visible only when illuminated from overhead, these inclusions created an interesting balance between transparency and chatoyancy that is rarely seen in cat's-eye gems.

GIA has examined very few phenakites in the laboratory, and to the best of our knowledge this is the first transparent chatoyant example identified in the lab. It is interesting to note that a 50.36 ct cat's-eye phenakite was documented in the Fall 2009 issue of *G&G* (GNI, p. 223). Unlike the colorless gem described here, which was reportedly from Sri Lanka, that phenakite was light

Figure 12. The synthetic diamond in figure 10 exhibited intense phosphorescence centered at 500 nm, as represented in this three-dimensional plot showing the decay with time. Due to the large initial intensity and long half-life, the sample had measurable phosphorescence spectra for more than three minutes (not visible at the scale of this diagram).

PHOSPHORESCENCE SPECTRA

Figure 13. This colorless and transparent phenakite cabochon, said to be from Sri Lanka, displays sharp chatoyancy.
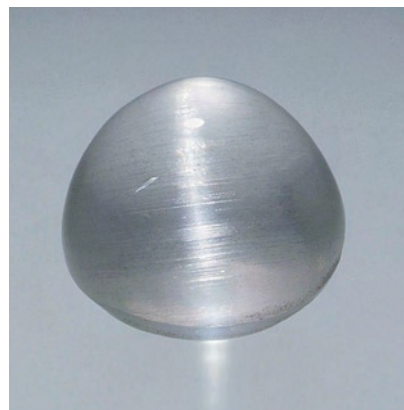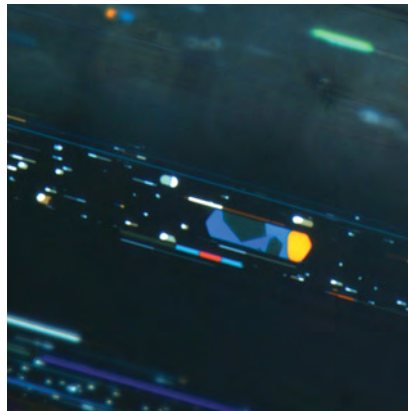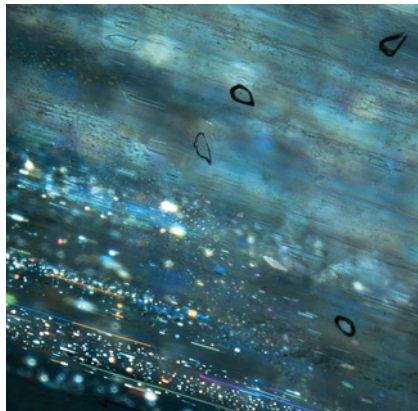
Figure 14. Aligned parallel to the optic axis, minute acicular tubes and iridescent platy voids are responsible for the chatoyancy in the phenakite cabochon (left, image height 2.2 mm). Somewhat larger angular inclusions showing high relief are also present. With higher magnification (right, image height 0.6 mm), some of the iridescent platy voids display complex multicomponent interiors.

brownish yellow and had been cut from a crystal mined in Madagascar.

John I. Koivula and Nathan Renfro

Blue SAPPHIRES, Diffusion Treated with both Titanium and Beryllium

The Bangkok laboratory recently received three blue sapphires (7.05–9.28 ct; see, e.g., figure 15) for identification. Microscopic examina-

Figure 15. This 9.28 ct sapphire was diffusion treated with both titanium and beryllium.

tion revealed that all three samples contained partially dissolved needles and heat-altered, partially healed fractures and crystals (figure 16). These inclusions were reminiscent of those seen in beryllium-diffused corundum (J. L. Emmett et al., "Beryllium diffusion of ruby and sapphire," Summer 2003 *G&G*, pp. 84–135).

When we immersed the stones in methylene iodide to examine the color zoning, however, we were surprised to find color concentrations along facet junctions and the girdle (figure 17). This is characteristic of blue sapphires that have undergone

diffusion treatment with titanium (R. E. Kane et al., "The identification of blue diffusion-treated sapphires," Summer 1990 *G&G*, pp. 115–133), which typically produces a thin layer of color at the surface. Normally, Ti-diffused blue sapphires are relatively clean; this is probably because the starting material commonly consists of Sri Lankan geuda stones that have been heat treated but failed to yield desirable colors. Included stones would have been broken during the first heating process, leaving only clean stones that were then Ti-diffused.

The three sapphires were analyzed by laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS), a routine procedure for heated corundum in the GIA Laboratory. As expected, the Ti concentrations at the surface were 293–579 ppma, much higher than in untreated blue sapphires. But the results also revealed high Be concentrations of 4.34–31.56 ppma, indicating diffusion with both titanium *and* beryllium.

The starting material for these double-diffused stones consisted of corundum with a relatively higher iron content [471–516 ppma, by energy-dispersive X-ray fluorescence (EDXRF) analysis], possibly from localities such as Songea or Tunduru, Tanzania. Titanium diffusion produces a favorable result when the starting material has a low Fe con-

Figure 16. These photomicrographs show partially dissolved needles (left, magnified 50×) and altered healed fractures (right, magnified 40×), which are typical of sapphires that have been subjected to high-temperature heat treatment.
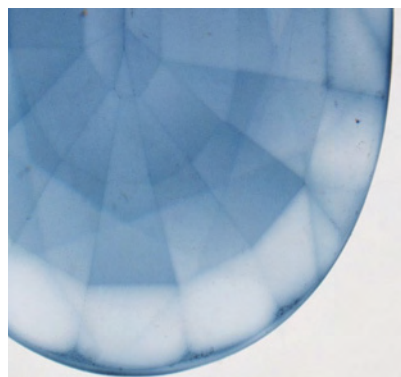
Figure 17. Viewed in immersion, the varying coloration and color concentrations along facet junctions and the girdle indicate that this sapphire was repolished after undergoing diffusion treatment. Magnified 7.5×.

tent, whereas sapphires with high Fe will turn dark blue. The overdark Ti-diffused stones could then have been diffused with Be in an attempt to lighten their color. Careful polishing would have been the last step to further lighten their appearance, as revealed by the color concentrations along their facet junctions and girdles.

Garry Du Toit
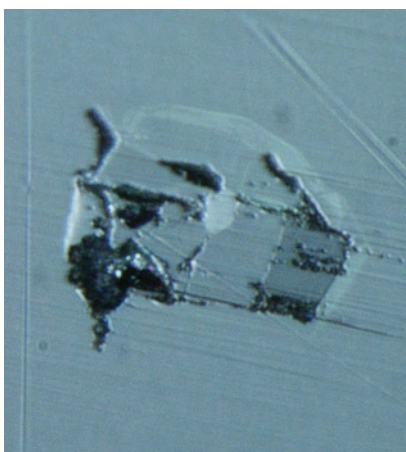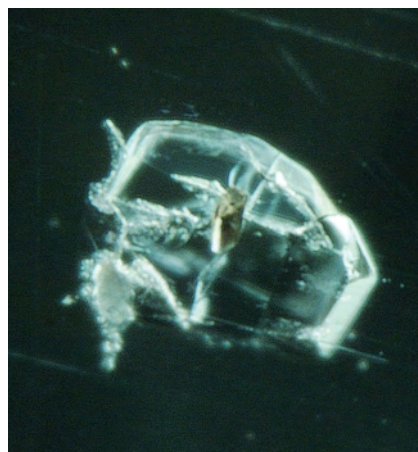
Interesting Inclusion Aggregate in TSAVORITE

One of the joys of gemology is discovering interesting features to share with others. For example, a gem may have an unexpected optical property, an unusual UV-visible spectrum, or a refractive index beyond the normal range. The most likely source of interesting features, though, is the gem's interior. Such was the case with a 5.44 ct green grossular (tsavorite) that was recently submitted to the Bangkok laboratory for a routine identification report. While it is not uncommon to find inclusions of various forms in tsavorite, this stone showed fine examples of long tubes, colorless crystals, and minute particles throughout. Some of the larger crystals exhibited clear stress halos.

It was one of the colorless crystals (figure 18, left) that caught our attention, since it clearly displayed a very small yellowish brown impurity. On closer examination, this impurity appeared to be a separate inclusion within the colorless crystal. Higher magnification revealed that the "colorless crystal" was actually an aggregate of *three* different materials, which were clearly visible in reflected light (figure 18, right).

Fortuitously, the inclusion was exposed on the surface. Raman analy-sis yielded good matches for zoisite and quartz in the colorless areas, and a less convincing match for sphene in the yellowish brown portion. However, the yellowish brown color was consistent with sphene, and based on its high reflectance, its refractive index appeared to be much greater than that of the other two components in the inclusion aggregate (which is also consistent with sphene). Further support for the identification of all three minerals comes from the geologic conditions in which tsavorite forms. Zoisite and grossular have similar chemical compositions and are often associated with each other (as with tsavorite and tanzanite; see, e.g., V. Pardieu and R. W. Hughes, "Tsavorite—the untamed beauty," *InColor*, Fall-Winter 2008–2009, pp. 12–20). In addition, quartz and sphene are known to be associated minerals surrounding tsavorite (K. Suwa et al., "Vanadian and vanadium grossulars from the Mozambique metamorphic rocks, Mgama Ridge, Kenya," *4th Preliminary Report of African Studies*, Nagoya University, 1979, pp. 87–95).

What appeared at low magnification to be one crystal exposed at the surface of the tsavorite turned out to be three separate minerals that had formed together—zoisite, quartz, and sphene. This is the first such aggregate inclusion in tsavorite seen by staff members in the Bangkok laboratory.

Nicholas Sturman and Garry Du Toit

Figure 18 The surface-reaching "crystal" evident within the host tsavorite (left, darkfield illumination) was actually composed of three minerals— zoisite, quartz, and probably sphene—each with a different surface luster (right, reflected light). Magnified 180×.

Uranium Mineral as Inclusions in TURQUOISE

Client requests to identify turquoise are relatively common at the GIA Laboratory, and there are seldom any surprises. Recently, however, turquoise beads and cabochons submitted by several different clients revealed some very unusual inclusions (figure 19). The source of the turquoise was stated to be China's Hubei Province.

Chinese turquoise is well known, but we were surprised to see bright yellow inclusions, identified by

Figure 19. The GIA Laboratory recently examined turquoise beads and cabochons represented as coming from China, which have bright yellow inclusions of uranium-bearing francevillite. This specimen weighs 6.72 ct.
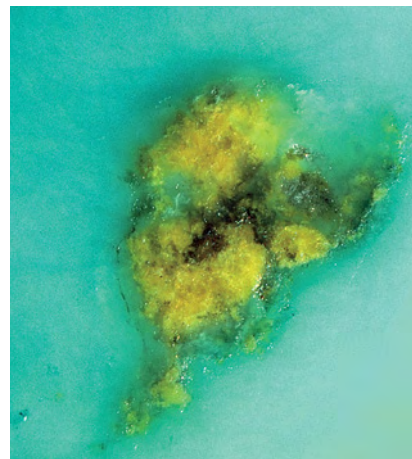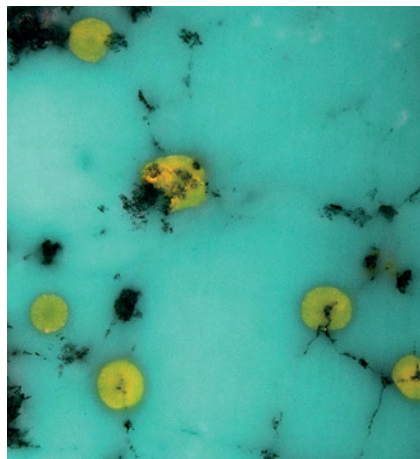
Figure 20. Vivid yellow inclusions of francevillite displaying a circular radial habit (left, the largest is 0.35 mm in diameter) are clearly visible in this turquoise, as are irregular masses of the uranium mineral (right, field of view 1.8 mm).

Raman analysis as francevillite [(Ba, Pb)$(UO_2)_2V_2O_8\cdot 5H_2O$], a hydrated barium uranium vanadate. Francevillite forms a solid-solution series with curienite [Pb$(UO_2)_2V_2O_8\cdot 5H_2O$], so a mixture of both could be present, though our Raman analysis clearly pointed to francevillite as the dominant mineral. Occurring as concretions with a radial habit, as circular to semicircular rings, and as nondescript masses and seam fillings (see, e.g., figure 20), these yellow inclusions stand out in sharp contrast with the blue background of their host. These francevillite inclusions were so obvious, sometimes even without magnification, that we are certain no such turquoise has entered our laboratory before. This suggests that a new find of turquoise is being mined.

Because uranium is a major constituent in both francevillite and curienite, we decided to check these turquoise samples for radioactivity with a Geiger counter. We thought they might register a readable signal, in the same way we can detect low levels of natural radiation in gems such as ekanite or zircon with this instrument. Our assumption proved to be correct: Very low levels of radiation were detected, supporting our Raman iden-

tification of this previously unknown inclusion in turquoise.

To detect radiation in gem materials, the GIA laboratory uses Victoreen 290 survey meters with so-called pancake probes, which are calibrated on an annual basis. To test an item, we first determine the current background radiation level (i.e., that present in our everyday environment from cosmic rays, radon, and other sources) and then check for radioactivity above that level in the gem material. Most of the turquoise samples with francevillite were only slightly above background. A few showed more elevated levels, reaching up to 7 or 8 millirems/hour, which is still considered very weak and generally harmless. By comparison, orange glazed Fiestaware ceramics, which have long been known to be somewhat radioactive, measure ~40 millirems/hour.

Nature surrounds us with radiation on a daily basis, coloring many objects in our lives. Gems such as pink tourmaline, green diamonds, and smoky quartz all derive their color from irradiation (see C. E. Ashbaugh, "Gemstone irradiation and radioactivity," Winter 1988 G&G, pp. 196–213). While turquoise

gets its blue bodycolor from copper, the bright yellow francevillite inclusions add an interesting aspect to their host.

It is important to note that although exposure to these levels of radiation is not considered significant, breathing dust that might be created during cutting should be avoided. For more information concerning radioactive minerals or radiation in general, we suggest contacting specialists in the field, such as the Health Physics Society (www.hps.org). In circumstances such as this, GIA Laboratory reports contain a comment stating "A naturally occurring accessory mineral is present that emits radiation detectable with a standard survey meter."

John Koivula and Shane McClure

COLORED STONES AND ORGANIC MATERIALS

Benitoite: Update on faceting and jewelry manufacturing. The world's only commercial source of gem-quality benitoite—the Benitoite Gem mine in San Benito County, California—was closed and reclaimed in June 2005 (see Fall 2005 Gem News International [GNI], p. 276). However,

Figure 1. Weighing a total of 52.39 carats, these 10 benitoites were mined and faceted by Benitoite Mining Inc. At 10.87 ct, the round brilliant in the center is the second-largest cut benitoite known. The matched pair of ovals weigh ~5.9 ct each, and the smallest stone pictured is 3.14 ct. Courtesy of BMI and Collector's Edge Minerals Inc.; photo by Robert Weldon.

a significant stockpile of faceting material was amassed by Benitoite Mining Inc. (BMI; Golden, Colorado) while working the deposit. At the 2009 Tucson gem shows, BMI president Bryan Lees had a collection of some of the best benitoites that had been cut from this stock, consisting of 10 stones that weighed a total of 52.39 carats (figure 1). This included a matched pair that weighed ~5.9 ct each, as well as a 10.87 ct round brilliant—the second-largest cut benitoite known, after the 15.42 ct stone on the cover of the Fall 1997 *G&G*. All the gems were faceted since 2002 by Ben Kho (Decatur, Georgia).

BMI has cut all of their stock that would yield stones >0.15 ct, and Mr. Lees estimates that these goods will last 3–5 years depending on the market's recovery from the global economic downturn. In addition, according to market demand, melee-sized stones are being cut into full round brilliants that measure 1–3.25 mm in diameter (see, e.g., Summer 2002 GNI, pp. 174–175). Mr. Lees stated that supplies of this material could last beyond five years.

The market for melee-size benitoite has been enhanced by the development of new ways to showcase this material. Jewelry lines that capitalize on the stone's brilliance and color variations (i.e., colorless to deep violetish blue) were developed by Paul Cory (Iteco Inc., Powell, Ohio) and Eric Braunwart (Columbia Gem House Inc., Vancouver, Washington; see, e.g., figure 2). Some of the rings and bracelets consist of dozens of mountings that are linked together in a way that allows freedom of movement. The white gold mountings are laser manufactured in China,

Figure 2. Jewelry designs containing melee-sized benitoite (here, 2.5 mm rounds) show the material's brilliance and range of color. The ring contains 58 benitoites set in individual mountings that are linked together so the design can move and bend, while the stones in the earrings (left and bottom) are set by conventional methods. Courtesy of Columbia Gem House Inc.; photo by Robert Weldon.

and the stones are set in the United States. Up to 400 benitoites have been set into a single bracelet, with individual stones generally ranging from 1.75 to 2.75 mm in diameter.

A chronology of the mining and processing activities by BMI, as well as many other details dating back to the discovery of the deposit, was recently published by W. E. Wilson ("The 100-year history of the Benitoite Gem mine, San Benito County, California," *Mineralogical Record*, Vol. 39, No. 1, 2008, pp. 13–42). In late June 2005, BMI sold the property to David Schreiner of Coalinga, California, who renamed it the California State Gem mine. The property was operated on a fee-collecting basis in 2007–2008 until the Bureau of Land Management closed the entire Clear Creek Management Area, due to public health concerns over exposure to asbestos that naturally occurs at several locations near the former benitoite mine.

Brendan M. Laurs

Large cat's-eye beryl from India. In February 2009, Dudley Blauwet (Dudley Blauwet Gems, Louisville, Colorado) loaned three large cat's-eye beryls (75.93–282.63 ct) and donated an additional (46.76 ct) stone to GIA for examination (figure 3). All these attractive semitransparent-to-

translucent oval cabochons exhibited a strong chatoyant band. According to Mr. Blauwet, the stones were obtained from near Shahpura, which is located 55 km north of Jaipur in Rajasthan State, India. He reported that there were several thousands of carats available in Jaipur, ranging from ~5 to 288 ct.

The following properties were determined on the four cabochons: color—yellow-green to brownish yellowish green; pleochroism—moderate greenish yellow to grayish green or moderate brownish yellow to yellowish green; spot RI—1.57–1.58; hydrostatic SG—2.69–2.71; and fluorescence—inert to long- and short-wave UV radiation. These properties are generally consistent with natural cat's-eye beryl (R. Webster, *Gems*, 5th ed., revised by P. G. Read, Butterworth-Heinemann, Oxford, UK, 1994, pp. 127–131). Observation of all cabochons with magnification and strong fiber-optic lighting revealed fine, iridescent, needle-like growth tubes, as well as numerous black and white needles, oriented parallel to the c-axis (figure 4); all were responsible for the strong chatoyancy. "Fingerprints" composed of transparent near-colorless crystals were also seen. Furthermore, all stones showed an absorption band of unknown origin at ~547 nm with the desk-model spectroscope.

Energy-dispersive X-ray fluorescence (EDXRF) analyses of these samples revealed major amounts of Al and Si, minor Fe, and traces of Cl, K, Ti, Cr, Zn, and Cs. The appreciable Fe content is not characteristic of beryl from India (see K. N. Babu and A. Sebastian, "On the genesis of Indian beryls," *Journal of the Geological Society of India*, Vol. 51, 1998, pp. 323–330). However, EDXRF is a bulk analysis technique that does not distinguish Fe concentra-

Figure 3. These cat's-eye beryl cabochons (46.76–282.63 ct), reportedly from Shahpura in India's Rajasthan State, show a sharp chatoyant band oriented perpendicular to the c-axis. Photo by Robert Weldon; the 46.76 ct stone (far right) is GIA Collection no. 37971.

Figure 4. Abundant growth tubes and needles oriented parallel to the c-axis are responsible for the chatoyancy of the beryl. Raman analysis of the needles identified hematite (black) and siderite (white). Photomicrograph by W. L. Win; field of view 3.8 mm.

tion between the host material and inclusions. Raman analysis identified hematite (Fe_2O_3) in the black needles and siderite ($FeCO_3$) in the white ones, which explains the relatively high concentrations of Fe in these samples.

Although Rajasthan State is a known source of gem beryl, large chatoyant material has not been reported previously to this contributor's knowledge.

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Emeralds recovered using new techniques at the Kagem mine, Zambia. The Kagem emerald mine in Zambia is the largest colored gemstone mine in the world, and since June 2008 it has been 75% owned by Gemfields Resources PLC (London). The mine is worked by large-scale open-pit methods using the latest in mining and processing technologies to expose the emerald-bearing zones and sort the mined material. However, past techniques for extracting emeralds from the surrounding rock have employed the use of crowbars, hammers, and chisels, which caused damage to the valuable gem rough.

Emeralds from Kagem and other mines in Zambia are typically hosted by phlogopite schist reaction zones adjacent to quartz-tourmaline veins (see J. C. Zwaan et al., "Emeralds from the Kafubu area, Zambia," Summer 2005 *G&G*, pp. 116–148). In late 2008, an unusually thick zone of mineralized quartz discovered at Kagem was found to contain emerald crystals with intense color and unusually high luster and clarity (see, e.g., figure 5). These high-quality emeralds were "frozen" within solid masses of quartz, so Gemfields approached Collector's Edge Minerals Inc. (CEMI) for assistance with preparing and marketing them to mineral connoisseurs. In March 2009, after they formed a partnership on this venture, CEMI proposed a new method for mining emeralds based on modern techniques used to extract delicate rhodochrosite specimens from the

Sweet Home mine in Colorado (see K. Knox and B. K. Lees, "Gem rhodochrosite from the Sweet Home mine, Colorado," Summer 1997 *G&G*, pp. 122–133). Specialized equipment, including a hydraulic splitter and diamond chainsaw, were shipped to Kagem, and in June CEMI's Graham Sutton trained their collecting personnel.

Although explosives are still used to excavate large areas of barren rock, the new collecting process is now employed near favorable zones for emeralds. First, a series of vertical holes are drilled 1–2 m deep along the top of benches that are 2.4-m high. Rock is then peeled away using the hydraulic splitter, which is designed to fit inside a 7-cm-diameter drill hole. Next, when emerald-rich zones are located, the diamond chainsaw is carefully used to remove the ore. Although this tool looks like an ordinary chainsaw, it is hydraulically mechanized to handle the rigors of rock cutting. The saw's blade contains sintered diamond teeth that can readily cut the rock in any direction needed, including straight into a mining face. The chainsaw has proved invaluable for extracting fragile specimens and gems.

The boulders and sawn blocks of mined material are sorted on site in a secure warehouse. Quartz-hosted samples showing potential to yield fine-quality mineral specimens are shipped to the trimming and cleaning lab at

Figure 5. At 10.7 cm tall, this specimen of emerald-in-quartz from Zambia's Kagem mine contains some fine gem-quality crystals. Courtesy of Collector's Edge Minerals Inc.

CEMI in Colorado. The first crystal specimens debuted at the Denver Gem and Mineral show in September 2009. As of early November 2009, 10 high-quality specimens and 20 moderate-value pieces had been prepared by painstakingly exposing the emeralds from the quartz matrix, revealing crystals that ranged up to 12 cm long and 2.5 cm in diameter. Processing of an additional boulder and several cobble-sized pieces is expected to yield a half-dozen high-quality specimens and 10–20 moderate-value pieces. It is hoped that more emerald-mineralized quartz lenses will be discovered as mining proceeds.

Gemfields has embraced the new collecting techniques at Kagem. In addition to greatly reducing damage to gem material and mineral specimens, these processes have improved productivity, since the workers spend less time hand chiseling the hard rock. An added benefit is security: With larger pieces being collected, less human contact with the emeralds decreases the potential for theft.

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Yellow grossular from Tanzania. New finds of grossular in yellow-to-green hues continue to be made in East Africa (e.g., Spring 2009 GNI, pp. 65–66). One of these was brought to GIA's attention in mid-2009 by Amarjit Saini (Mobu Gems, Los Angeles). According to his partner, Peter C. L. Pereira (Isle Of Gems, Arusha, Tanzania), the garnet is found in the Lelatema Mountains, ~70 km southeast of Arusha and 30 km east of Merelani. The deposit has been mined for several years, but only recently (2007–2008) has it yielded significant—although limited—production. The vast majority of the rough weighs <1 g, with ~1 g sizes uncommon and 2+ g pieces rare. The color varies from "golden" yellow to greenish yellow, and less commonly orange (i.e., "Fanta" color). Most of the facetable material is slightly to moderately included. The cut stones typically weigh <2 ct, although Mr. Pereira knew of a few that weighed ~5 ct. The garnet is sometimes sold as "Tsavo Golden."

Mr. Saini donated three faceted samples of the yellow grossular (figure 6) to GIA, and the following gemological properties were obtained: color—light slightly orangy yellow to light orange-yellow; RI—1.738; hydrostatic SG—3.61–3.62; fluorescence—weak reddish orange to long-wave UV radiation, and weak to moderate yellowish orange to short-wave UV; and a weak absorption line seen at 430 nm with the desk-model spectroscope. These properties are consistent with grossular (R. Webster, *Gems*, 5th ed., Ed. by P. G. Read, Butterworth-Heinemann, Oxford, UK, 1994, pp. 201–202). Microscopic examination showed the stones were largely free of inclusions and growth features, except for some transparent crystals that were identified by Raman spectroscopy as apatite (figure 7).

Chemical analysis of all three stones by laser ablation–inductively coupled plasma–mass spectrometry measured average values of 4600 ppmw Fe and 3300 ppmw Mn. The chromophores Cr and V, which are often found in yellowish green to green grossular from East Africa,

Figure 6. These grossulars (1.51–2.29 ct) were reportedly mined from the Lelatema Mountains in Tanzania. Photo by Robert Weldon.

were present in negligible quantities (<50 ppmw). The ultraviolet-visible (UV-Vis) absorption spectra (figure 8) showed strong Mn^{2+}-related features, including a cutoff at 372 nm and peaks at 409, 419, and 430 nm. Very weak features at 504 and 690 nm were due to Fe^{2+}. The yellow coloration of these garnets is due to Mn^{2+}, as described previously for yellow to greenish yellow grossulars from East Africa (Winter 1991 Gem News, p. 258; Winter 2005 GNI, pp. 352–353).

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Figure 7. The only inclusions present in the grossulars were transparent crystals of apatite. Photomicrograph by D. Beaton; field of view 1.6 mm.

UV-VIS ABSORPTION SPECTRUM
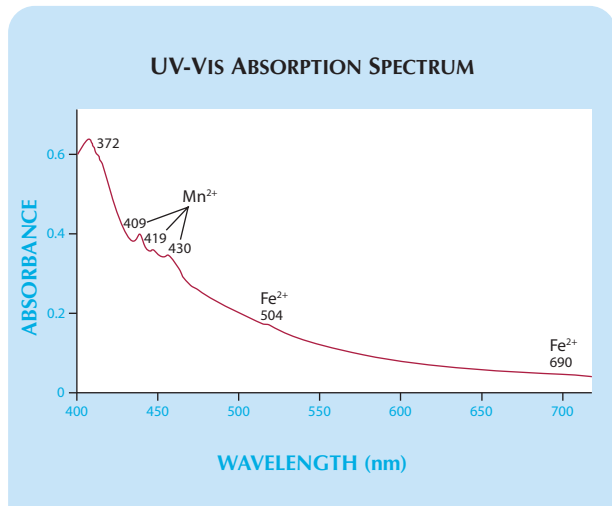
Figure 8. The UV-Vis spectra of the yellow grossulars displayed strong Mn^{2+}-related features. Very weak absorptions attributed to Fe^{2+} were present at 504 and 690 nm.

A most unusual blister pearl. A *blister pearl* is a pearl attached to the shell of its mollusk host, and may be natural or cultured. A natural blister pearl may result when a pearl that formed loosely within the mantle of a mollusk later comes into contact with the inner shell, subsequently becoming attached as further layers of nacre are laid over it. Natural blister pearls also form when parasites (worms and other organisms) attack the mollusk, often burrowing through the shell from outside. The mollusk defends itself by forming nacre around the intruder, and the resulting blister pearls sometimes resemble the original animal.

We recently had an opportunity to analyze a rare natural blister pearl in the shape of a fish or an eel that was found in a large *Pinctada maxima* oyster (figure 9). This bivalve, which originated from the Philippines, measured 25×22 cm; the blister pearl was 11 cm long. To investi-

gate the origin of this sample, we analyzed it with Gemlab's "Blackbox" prototype radiography system using a high-resolution digital X-ray detector. The X-radiographs clearly showed the remains of a slender, elongated fish inside the blister pearl (figure 10). Its skull and a pectoral fin were especially detailed.

The fish was identified as a member of the pearlfish family (Carapidae), most likely the species *Onuxodon parvibrachium* (described by Fowler, 1927). This species is known as the oyster pearlfish (figure 10, inset) because of its commensalism with large bivalves such as the various *Pinctada* species (D. F. Markle and J. E. Olney, "Systematics of the pearlfishes (Pisces: Carapidae)," *Bulletin of Marine Science*, No. 47, Vol. 2, 1990, pp. 269–410). In a commensal relationship, two organisms live together and one profits while the other neither benefits nor is harmed. In this case, the fish benefits from the shelter of the mollusk's shell.

Figure 9. This Pinctada maxima *shell (25×22 cm) contains a fish-shaped blister pearl. Photo by T. Hainschwang.*
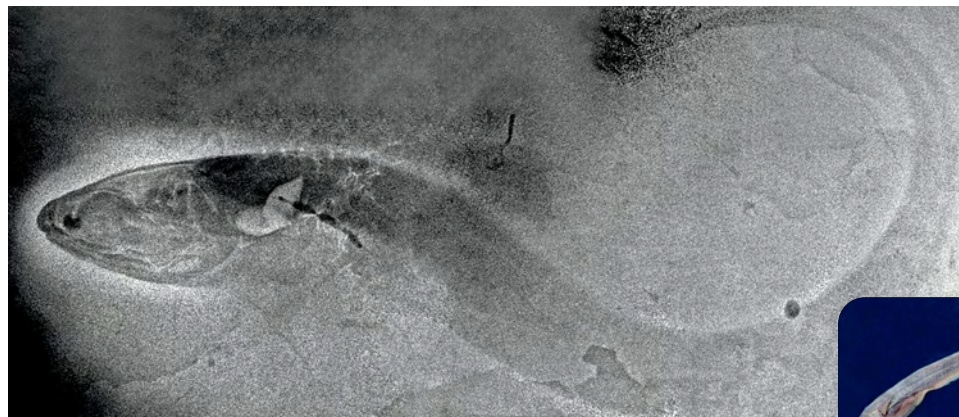
Figure 10. An X-radiograph reveals the remains of a fish within the blister pearl. For comparison, the inset photo shows a preserved specimen of the pearlfish Onuxodon parvibrachium *(source: National Digital Archive Program, Taiwan).*

When such a fish dies inside the host, it can be covered by nacre with the remarkable result shown here. Similar blister pearls have been reported from *Carapus dubius* (Putnam, 1874), the Pacific pearlfish.

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Myanmar cultured pearl production and new gem localities. Each year, Myanmar's eight pearl farms (joint ventures between the government and Japanese, Australian, and Thai companies) produce some 400,000 cultured pearls (table 1). The output has been restricted by limitations on the number of pearl oysters. The largest farms offered 50,000–100,000 cultured pearls in the government's Pearl Emporiums, which are held once or twice a year. The 27th emporium was held September 23–25, 2009. Yangon was the site of the first 26 emporiums, but this year's event took place in Naypyidaw (south of Mandalay). Tender and auction sales for the 424 lots of cultured pearls totaled ~US$798,000, the most in 18 years. In all, 69% of the lots were sold. This emporium also featured lectures that were open to the public on pearl farming, sorting, and other topics.

A new production of spinel occurred in August 2009 at Bawma, located 9 km northwest of Mogok at coordinates 22°57′ N, 96°25′ E (elevation ~1220 m). Mostly red and purple spinel was produced, and the largest pieces weighed 1+ g. The spinel is associated with metacarbonate rocks and syenite. The deposit has been known since before World War II, but the recent finds created a gem rush that prompted the township government to stop mining activities. Nearby, colorless crystals of jeremejevite that exceeded 2 cm long were found in early 2009 at Kyauksin village (elevation ~1525 m). The jeremejevite was initially mistaken for quartz by local gem miners. In Kachin State, a new deposit of translucent "moss" green hydrogrossular was found in 2008 near Namhpu. The garnet was found in an outcrop near a stream that has produced ruby.

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Phenakite from Nigeria. Phenakite (Be_2SiO_4) is an unusual mineral that is known in gem quality from some granitic pegmatites and schist-hosted emerald/alexandrite deposits. In October 2009, Dr. Robert Lavinsky (iRocks.com, Dallas, Texas) informed this contributor about a new find of gem-quality colorless phenakite crystals from Nigeria (e.g., figure 11). In partnership with Bill Larson (Pala International, Fallbrook, California), he obtained five crystals that were selected from a parcel offered in Bangkok. In September he

TABLE 1. Annual production of cultured pearls in Myanmar.[a]

Year	Number	Weight (momme)
2006–2007	410,791	240,596
2007–2008	443,810	235,917
2008–2009	437,181	238,744
2009 (as of August)	92,178	40,500

[a] *Source: Biweekly Burmese journals, September 4 and 25, 2009.*

obtained another ~30 crystals at the Denver Gem and Mineral Show that ranged up to 5.1 × 3.8 × 3.4 cm. Mr. Larson reported the material was found in August 2009 in the Jos region of central Nigeria, where it is referred to as *okuta didan* (meaning "shining stone" in the local language). The crystals are notable for their transparency and bright, lustrous appearance; they commonly show complex surface patterns that appear to be due to chemical etching.

Although much of the phenakite is sold as mineral specimens, some of the material has been faceted into attractive gemstones. Mark Smith (Thai Lanka Trading Ltd. Part., Bangkok) reported cutting ~100 stones as of October 2009, from a 973 g parcel containing about 45

Figure 11. Nigeria is the source of this phenakite crystal (4.4 × 2.9 × 2.3 cm), which displays complex surface patterns that are characteristic of material from this locality. Courtesy of iRocks.com.

Figure 12. This Nigerian phenakite is impressive for its size (83.45 ct) and transparency. Courtesy of Herb Obodda (H. Obodda, Short Hills, New Jersey); photo by Thai Lanka Trading Ltd. Part.

pieces (typically 10–65 g each) that he obtained in late August. Most of the resulting cut stones weighed 1–10 ct, but larger gems up to 23 ct (eye clean) and 33 ct (very slightly included) were also faceted. The largest cut phenakite weighed 83.45 ct and was virtually free of inclusions (figure 12). Mr. Smith sold a 136.2 g crystal that he

Figure 13. The ruby mining site near the village of M'sawize, Mozambique, is located within the Niassa National Reserve. Photo by V. Pardieu.

estimated would facet an eye-clean 200 ct gemstone.

A literature search revealed only one reference to phenakite from Nigeria: J. Malley and A. Banerjee, "Farbloser Phenakit aus Nigeria [Colorless phenakite from Nigeria]," *Kurzmitteilungen aus dem Institut fuer Edelsteinforschung der Johannes-Gutenberg-Universitaet Mainz*, Vol. 2, 1987, 3 pp. With this new find, we can add one more mineral to the list of high-quality gems produced from Nigeria, which includes tourmaline, topaz, emerald, aquamarine, various garnets, sapphire, and more (J.-C. Michelou, "Le Nigeria. Source de pierres de couleur," *Revue de Gemmologie*, No. 159, 2007, pp. 30–41).

Brendan M. Laurs

Update on rubies from Mozambique. In September 2008, rubies appeared in the Tanzanian market that came from a new mine in the M'sawize area of Niassa Province, Mozambique. Then, in February 2009, a second ruby deposit was discovered in the neighboring province of Cabo Delgado, between Pemba and Montepuez. The GIA Laboratory has described the Mozambique rubies in two reports (see V. Pardieu et al., www.giathai.net/pdf/ Niassa_Mozambique_Ruby_September13_2009.pdf and S. F. McClure and J. I. Koivula, Fall 2009 GNI, pp. 224–226). In November 2009, one of these contributors (VP) visited M'sawize to document the deposit and obtain samples for GIA's research collection.

The mining site (figure 13) is located ~40 km southeast of M'sawize, in a remote area within the Niassa National Reserve. In July 2009, artisanal miners were expelled from the area by government authorities, and the Reserve continues to search for a solution to deal with illegal digging in this protected area. The area mined for rubies measured ~400 × 200 m, and the hand-dug pits were up to 12 m deep. The pits exploited the eluvium as well as the underlying primary deposit. The rubies formed in veins intruding altered gneiss, possibly of dioritic composition (Dr. Walter Balmer, pers. comm., 2009). The following minerals associated with ruby were identified by one of us (PL): actinolite, anorthite, scapolite, diopside, and epidote. Mica and red garnet were also noted on site. The rubies seen in M'sawize were very similar to those described by Pardieu et al. (2009), ranging from pink to dark red, usually with a tabular habit and weighing up to 40 g. Some showed a silky appearance.

We also attempted to visit the Montepuez deposit, but were unsuccessful due to continued tensions between the police and illegal miners. (In October 2009, the local authorities had convinced most of the miners and dealers to leave the area, while the owner of the private game farm encompassing the deposit was granted a mining license and entered into a partnership with a Thai company.) Several parcels of rubies represented as being from Montepuez (e.g., figure 14) were seen in the Mozambique cities of Nampula and Pemba. The material was similar to the stones described by McClure and Koivula (2009), and was usually a deeper red and flatter in habit than the

M'sawize rubies. Mineral inclusions (mainly amphibole) were more common, and many stones were milky.

Several fine, untreated faceted M'sawize rubies (often called "Mozambique," "Lichinga," or "Niassa" rubies in the trade) weighing up to 5 ct have appeared in the Bangkok market since late 2008, though most good-quality untreated stones have weighed <2 ct. Montepuez material, in similar sizes and qualities, appeared in Bangkok during the summer of 2009. According to Thai buyers and treaters, only ~5–10% of the Mozambique production is fine enough to be sold without heating, while the lower-quality material (~70–85% of the production) is suitable for lead-glass filling. The remainder of the rough responds to conventional heat treatment in a borax flux. Glass-filled Mozambique rubies (up to 20 ct) actually have been circulating in the Thai market since 2006—probably from elsewhere in Mozambique, such as Ruombeze (see Pardieu et al., 2009).

If mining disputes at the two new Mozambique deposits can be resolved, they could become important sources of African rubies that offer attractive alternatives to Burmese goods.

The authors thank the Niassa National Reserve and Moses Konate of Mozambique Gems (Nampula) for their support during their expeditions.

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Transparent, bright blue sodalite from Afghanistan. At the 2009 Denver Gem and Mineral show, Rob Lavinsky (iRocks.com, Dallas, Texas) had two specimens of sodalite that were remarkable for the transparency and bright color of their crystals (e.g., figure 15). The pieces were reportedly

Figure 15. These transparent and brightly colored sodalite crystals (up to ~7 mm) were reportedly recovered from a deposit near the lapis lazuli mines in Badakhshan, Afghanistan. Courtesy of iRocks.com; photo by Joe Budd.

Figure 14. Ruby from Montepuez (here, up to 17 mm) is typically deeper red and flatter in habit than the stones from Niassa. Photo by V. Pardieu.

mined in May 2009 from the Kokcha Valley in Badakhshan, Afghanistan. This area also produces other intense blue sodalite-group minerals, such as haüyne and lazurite. However, the identity of these crystals as sodalite was confirmed by Dr. Robert Downs (University of Arizona, Tucson), who analyzed a fragment from one of the specimens using single-crystal X-ray diffraction analysis and Raman spectroscopy.

The sodalite occurs on a light-colored crystalline matrix with scattered small crystals of a brassy mineral that is probably pyrite. X-ray diffraction and Raman analysis of the matrix by Dr. Downs identified it as native sulfur. One of Mr. Lavinsky's specimens had sodalite crystals that were surrounded by a massive bright yellow mineral, apparently also native sulfur.

Although only a limited amount of this sodalite has been found—and the well-formed crystals are being sold exclusively as mineral specimens—the possibility exists that this attractive transparent material could be cut into brightly colored gems, which might contain unusual inclusions such as native sulfur.

Brendan M. Laurs

Pseudo-chatoyancy and pseudo-asterism in sphalerite from Spain. Sphalerite is popular among gem collectors for its extremely high refractive index and dispersion, but there have been no reports of phenomenal stones. Recently, however, we examined several sphalerite cabochons (e.g., figure 16) that exhibited sharp cat's-eyes, and two others that showed weak asterism (four- and six-rayed stars). These samples were represented as being from the Picos de Europa deposit in Spain, by far the world's most important source of gemmy sphalerite.

We identified the stones as sphalerite based on the following gemological properties: RI—over the limit of a standard refractometer, SG—4.08, optic character—isotropic, UV fluorescence—inert, and no lines visible with a handheld spectroscope. They ranged from yellow to orange, often showing both colors.

Figure 16. The cat's-eye and star effects of these sphalerites (18 and 20 mm long) are due to scratches on the base that were probably created during polishing. Photo by J. Hyršl.

With further examination, the origin of the chatoyancy and asterism became evident. When the cabochons were viewed with high magnification, tiny parallel polishing scratches were revealed on their bottom surfaces (figure 17). These scratches were usually slightly curved, resembling the striae characteristic of Verneuil synthetics. The best way to recognize the scratches was to sharpen the focus of the microscope. Because they were not three-dimensional, they could only be seen in one plane on the surface.

The cat's-eye and star effects shown by these sphalerites are very similar to the manufactured asterism described by S. F. McClure and J. I. Koivula ("A new method for imitating asterism," Summer 2001 *G&G*, pp. 124–128) and by K. Schmetzer and M. Steinbach ("Fake asterism—two examples," *Journal of Gemmology*, Vol. 28, No. 1, 2002, pp. 41–42). In this case, the phenomena probably were not

Figure 17. Polish lines on the bases of the sphalerite cabochons were responsible for the phenomena. Photomicrograph by J. Hyršl; field of view 2 mm.

intentional, because the gems were offered simply as cabochons, and not as star or cat's-eye sphalerites.

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Update on Cu-bearing tourmaline mining in Mozambique. The Mavuco area of Mozambique is famous for producing large quantities of Paraíba-type tourmaline, particularly in 2006–2007 (see, e.g., B. M. Laurs et al., "Copper-bearing [Paraíba-type] tourmaline from Mozambique," Spring 2008 *G&G*, pp. 4–31). Most of the stones have come from artisanal miners, although one company—Mozambique Gems, owned by Moses Konate—has been preparing for a major mechanized operation. In September 2009, these contributors visited the Mozambique Gems claim and documented these developments.

There were 45 people actively working at the mine, including six Brazilian technicians who constructed the washing plant. After two years in construction, this washing plant became fully functional in June 2009. Preliminary mining has taken place in open pits in three areas of the claim that were dug in June-July 2009. The laterite overburden was removed using an excavator, and the gem-bearing gravel (locally called "cascalho") was stockpiled and washed. The company's goal is to process six to eight truckloads (each about 20 tonnes) of material per day.

The processing of the gravels begins with two powerful water cannons that wash out the mud and fine-grained sediments. The muddy water is routed to a series of basins that act as settling ponds and reservoirs for the dry season. The gravels are sorted through a number of vibrating screens, each with mesh that is progressively smaller, and the sized material is spread onto white tables for handpicking of the tourmaline (figure 18). The gems are placed in secure boxes under the sorting tables.

According to production records provided by mine personnel, the first two months of operation yielded >180 kg of black tourmaline and 8 kg of colored Paraíba-type tourmaline. Most of the colored tourmaline (about 70%) was

Figure 18. At the Mozambique Gems processing plant, the washed gravels are placed on white tables for hand picking of the tourmaline. Photo by V. Pardieu.

small (i.e., <2 g; see figure 19), although some fine clean pieces up to 30–40 grams were found. An average of 100–300 g of Paraíba-type tourmaline were produced daily, on a shift of 20 days per month; the best daily production has approached 2 kg. The material is sent to Brazil where it is cleaned with acid, heat treated, and then faceted.

No mechanized mining activity was seen outside the Mozambique Gems claim. Areas to the south and west of the claim were worked by independent miners from 2005 until early 2009, when the deposits were considered exhausted. These diggings, referred to as the Banco area, were the source of most of the Mozambique Cu-bearing tourmaline that entered the world markets, particularly in Bangkok and Hong Kong. After the Banco was exhausted, the miners attempted to invade the Mozambique Gems claim. In response, the police removed them from the entire area. Nevertheless, some illegal digging continues to take place at night, as revealed by a few freshly dug pits in the Banco area.

Mozambique Gems has continued its commitment to mine their claim in a professional, environmentally responsible manner that benefits the local community and minimizes impact on the area they are mining. The company will remediate the open pits by filling them with stockpiled soil and planting cashew nut trees. Their entire project appeared quite ambitious and well managed. If ultimately successful, it will serve as a positive example to follow in Mozambique and elsewhere in Africa.

Vincent Pardieu, Stephane Jacquat,
Lou Pierre Bryl, and Jean Baptiste Senoble

New find of pink-to-red tourmaline in Nigeria. Western Nigeria has been an important source of fine-quality gem tourmaline for several years, particularly of pink stones in

Figure 20. This 7 kg tourmaline from Nigeria's Oyo Valley contains large areas of clean, brightly colored gem material. Photo by Richard Barker.

Figure 19. The Cu-bearing tourmalines are recovered as waterworn pebbles in a variety of colors. Here, unheated stones are shown together with descriptions of their predicted coloration after heat treatment. Photo by V. Pardieu.

the late 1990s (Winter 1998 Gem News, pp. 298–299). Recently, a significant deposit of pink-to-red tourmaline was found in the Oyo Valley of western Nigeria, according to Bill and Richard Barker (Barker & Co., Scottsdale, Arizona). In August 2009, they obtained a 20 kg parcel of this tourmaline that was notable for its high transparency and bright coloration. The largest piece weighed 7 kg and contained abundant gem-quality transparent areas (figure 20). It was so big (up to 28 cm in diameter and nearly 13 cm thick) that a large tile saw was required to make the initial cuts. As of November 2009, ~1,000 stones had been polished, weighing nearly 7,000 carats. Cutting of the stones to contain relatively few inclusions resulted in an overall yield of approximately 15%. The material fell into three main color groups: slightly purplish red (50%), darker red (10%), and "bubble gum" pink (40%). The largest stone weighed 53.45 ct, and several more were produced in the 20–40 ct range, as well as numerous calibrated goods ranging from 3 mm rounds to 14 × 10 mm ovals and cushions. The abundance of clean material showing consistent color has facilitated the creation of several necklace suites (e.g., figure 21).

According to Mr. Barker's supplier in Nigeria, the deposit shows good potential for yielding additional pink-to-red tourmaline for the jewelry market.

Brendan M. Laurs

SYNTHETICS AND SIMULANTS

Hydrothermal synthetic emerald sold as natural rough from Russia. Recently, the Dubai Gemstone Laboratory received an ~21.8 g intense green sample for identification (figure 22). The client who submitted the piece said it was selected from a parcel of some 800 g that had been repre-

Figure 21. The 17 Nigerian tourmalines in this necklace set (7.84–24.00 ct; total weight ~250 carats) and the other stones in the center show the bright color and transparency of this new material. Photo by Robert Weldon.

sented as natural Russian emerald. He thought the parcel might consist of assembled material because all the crys-

Figure 22. This ~21.8 g sample, represented as natural emerald from Russia, proved to be a cleverly fashioned hydrothermally grown synthetic. The view on the right reveals the presence of a colorless seed plate. Photos by S. Singbamroong, © Dubai Gemstone Laboratory.

tals showed a noticeable colorless layer in their centers.

The sample had a hexagonal prism shape and a rough-textured surface with small patches of an off-white clay-like material on the "prism faces"; the colorless layer reported by the client was easily visible (again, see figure 22). This layer had the typical appearance of a seed plate used to grow hydrothermal synthetic emerald, rather than the separation plane that is common in assembled stones. The sample also had an uneven, undulated surface on one of the "prism faces," oriented parallel to the seed plate (figure 23). When viewed with magnification while immersed in benzyl benzoate, it displayed wavy growth patterns and planar zoning parallel to the seed plate (figure 24). All of these features are characteristic of hydrothermal synthetic emerald. Also present were stress cracks near the contact zone between the seed and the overgrowth. Fourier-transform infrared (FTIR) spectroscopy and EDXRF analysis confirmed the emerald's hydrothermal synthetic origin.

This sample had clearly been fashioned to resemble natural emerald rough. A buyer with no experience or access to laboratory expertise could make a costly mistake when presented with this material in the field.

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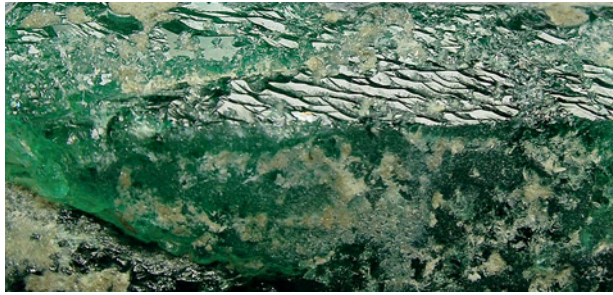
Figure 23. An uneven, undulated surface, such as that commonly observed on hydrothermal synthetic emerald, is present on one of the "prism" faces. Photomicrograph by S. Singbamroong, © Dubai Gemstone Laboratory.

Figure 24. Immersion reveals wavy growth patterns and planar zoning parallel to the colorless seed, and also stress cracks near the seed, in the synthetic emerald "crystal." Photomicrograph by S. Singbamroong, magnified 18×; © Dubai Gemstone Laboratory.

High-RI barium-zirconium glass imitation of peridot and other gems. A 36 ct green oval modified brilliant (figure 25), thought to be peridot, was sent to Gemlab for identification. The very high brilliance and dispersion were more consistent with zircon than peridot. However, microscopic observation indicated that the sample was isotropic and free of inclusions except for a gas bubble ~25 µm in diameter, which indicated either glass or a melt synthetic.

When examined between crossed polarizers, the sample showed no strain pattern. Its RI was above the limit of the refractometer (>1.81), and the hydrostatic SG was 4.65. It was inert to long- and short-wave UV radiation, and also to the high-power UV excitation of the Gemlab UV microscope prototype (245–385 nm broadband emission, 200 W xenon source).

The sample's infrared reflectance spectrum (figure 26) did not correspond to that of ordinary lead-oxide silica glass, which would have explained the optical properties.

The only matching reference spectrum belonged to a barium glass that was analyzed some time ago. EDXRF spectroscopy revealed that the sample was indeed barium rich, and it contained significant quantities of zirconium, plus some hafnium and germanium. Interestingly, this glass had almost no silicon. Barium-rich glass has been identified before (Winter 2005 GNI, pp. 362–363), but it was chemically and optically different from the high-RI glass described here. A glass with similar optical properties (RI = 2.0 and SG = 4.59) seen in green and other colors was reported in the Winter 1993 GNI section (p. 289), but no chemical composition was given.

Very seldom seen as a gem imitation thus far, this attractive barium-zirconium glass may become more com-

Figure 25. This brilliant, dispersive green sample, sold as peridot, is actually a barium-rich glass. Photo by T. Hainschwang.

Figure 26. Reflectance FTIR spectroscopy showed that the barium-rich glass in figure 25 is very different from the reference sample of the more commonly seen borosilicate glass.
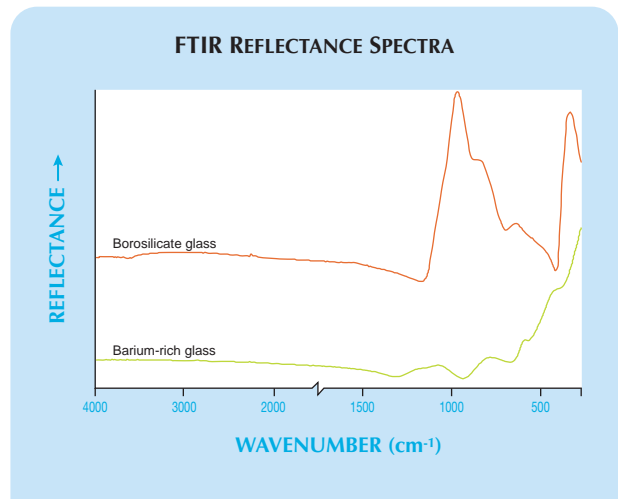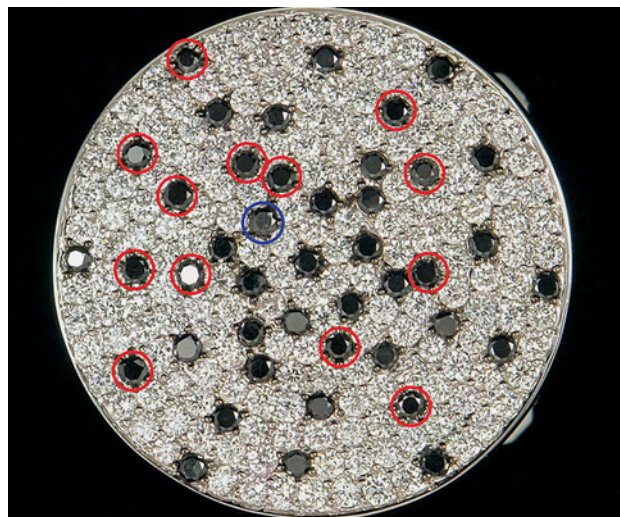
Figure 27. In this ring, the 13 red circles are black diamonds and the other 30 black stones are synthetic moissanite, one of which has crystalline silicon inclusions (blue circle). Photo by Li Haibo.
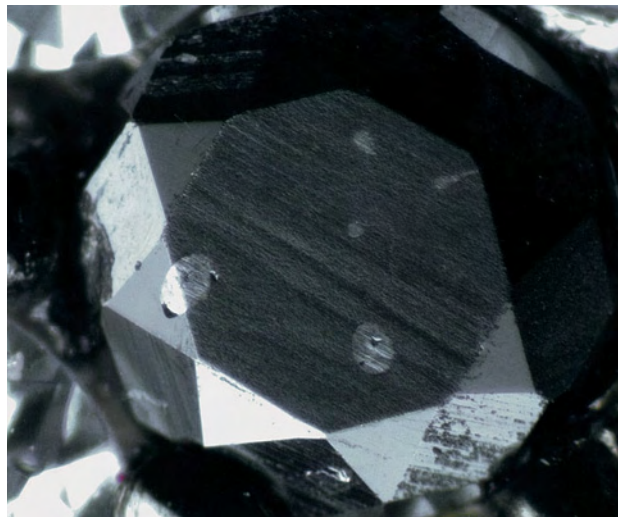
Figure 28. Five inclusions of crystalline silicon (the areas with silvery luster) are seen in the table of this black synthetic moissanite. Photomicrograph by Li Haibo; magnified 50×.

mon in the trade as an imitation of stones such as demantoid, zircon, and peridot.

Thomas Hainschwang

Silicon inclusions in black synthetic moissanite. After black-and-white jewelry became fashionable in the late 1990s, the demand for black diamonds soon exceeded supply. As a result, more treated black diamonds and black diamond simulants have entered the market. In February 2009, Japan's GAAJ-Zenhokyo laboratory issued an advisory regarding black synthetic moissanites mixed with black diamonds in jewelry (H. Kitawaki, "Lab Alert: Black moissanite," February 2, 2009, www.gaaj-zenhokyo.co.jp/researchroom/kanbetu/2009/2009_01_02-01en.html).

Recently, 21 pieces of black-and-white diamond jewelry were submitted to our laboratory by a single client for identification reports. We examined all the stones with standard gemological testing and FTIR and Raman spectroscopy. These techniques proved that 10 of the jewelry pieces contained black synthetic moissanite—229 of the 1,690 black samples we studied (see, e.g., figure 27).

Microscopic observation of genuine black diamonds with fiber-optic illumination typically reveals black needle-like inclusions of graphite scattered throughout. Black synthetic moissanite, however, is opaque even under strong light, and it also typically displays a rough surface, blunt facet edges, and various growth defects (i.e., cavities, micropipes, etc.) that are very different from diamond (Zhang Beili, *Systematic Gemmology*, Geological Publishing House Press, Beijing, 2006). Interestingly, more than 20 of the 229 black synthetic moissanites identified contained irregular-shaped surface-reaching inclusions with a silvery luster in reflected light (figure 28).

Raman spectroscopy of these inclusions identified them as crystalline silicon. To our knowledge, silicon inclusions in black synthetic moissanite mixed with black diamond jewelry have not been reported previously. They suggest that these black synthetic moissanites were not grown by the seeded sublimation process used to produce typical near-colorless synthetic moissanite for jewelry use, in which SiC is vaporized and then condensed without ever passing through the liquid state (K. Nassau et al., "Synthetic moissanite: A new diamond substitute," Winter 1997 *G&G*, pp. 260–275). Silicon inclusions have not been reported in synthetic moissanite grown by seeded sublimation, but they are known in synthetic moissanite grown by the physical vapor transport (PVT) technique in China (see Zhi-Zhan Chen et al., "Growth of large 6H-SiC single crystals," *Journal of Inorganic Materials*, Vol. 17, No. 4, 2002, pp. 685–690). Therefore, the black synthetic moissanites in this study were probably grown with the PVT technique.

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Dyed sillimanite as an emerald imitation. The Gemlab laboratory recently received for analysis three stones (figure 29, left) that had been purchased in India from a dealer who guaranteed they were natural, untreated emeralds. Ranging from ~14.5 to 43.75 ct, they were translucent and had a saturated green color. Significantly, they appeared to be filled with fibrous inclusions. Microscopic examination showed that these fibers were not inclusions; rather, the material itself had a fibrous structure (figure 29, right). Further, the green color was concentrated within this structure, indicating that the material was not emerald but a dyed imitation.

The samples were analyzed by FTIR spectroscopy, first

Figure 29. These three dyed sillimanites were represented as emeralds (left). With magnification, their fibrous structure showed green color concentrations, indicating the presence of dye (right, image width 11.5 mm). Photos by T. Hainschwang.
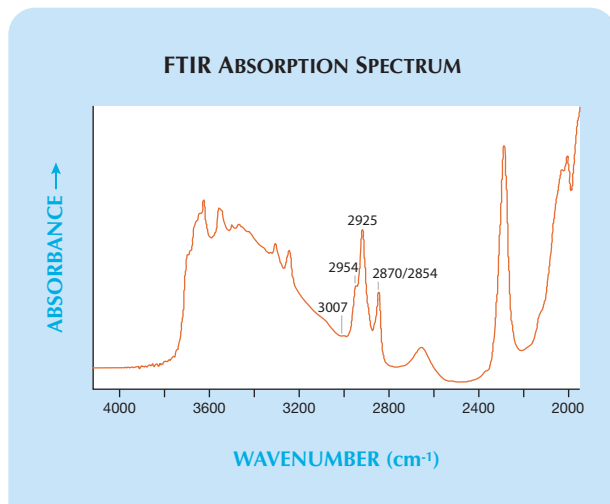
Figure 30. The FTIR absorption spectra of the sillimanite indicated significant amounts of oil, as shown by the labeled peaks.

in reflectance mode to determine the mineral species and then in transmission mode to detect any organic substances. The reflectance spectra identified all three samples as sillimanite (Al_2SiO_5). The absorption spectra showed that they contained significant quantities of oil (figure 30). Dyed sillimanite has reportedly been used to imitate a variety of materials (see, e.g., Fall 2005 GNI, p. 274). Due to its fibrous structure (which gives it the com-monly used name *fibrolite*), sillimanite easily accepts dyes, allowing colored oils to penetrate deep into the stone.

Thomas Hainschwang

TREATMENTS

Dyed pink alabaster. A massive variety of the mineral gypsum ($CaSO_4 \cdot 2H_2O$), alabaster is usually colorless, white, or gray, with various shades of yellow, red, brown, or even black due to impurities. Gypsum has a Mohs hardness of 2 and is therefore too soft for use as a gem, but it has been fashioned into beads and carvings. Recently, however, a cabochon of alabaster (figure 31) was submitted to the Gem Testing Laboratory of Jaipur for identification, and it had an unexpected orangy pink color.

At first glance, the 14.32 ct specimen (17.59 × 12.86 × 8.07 mm) resembled chalcedony or opal because of its translucency. However, its luster was much too dull, and it had a distinctive waxy appearance. Fine chips on the dome revealed a powdery white composition (again, see figure 31). The powder was easily removed when wiped with a finger, indicating a very low hardness; this was confirmed by scratching an inconspicuous part of the cabochon with a fingernail. Hence, the specimen could not have been opal or chalcedony.

Such low hardness pointed to gypsum, which was confirmed by the spot RI of 1.52 and hydrostatic SG of 2.31. It had a patchy yellow-orange reaction to UV radiation, with a stronger reaction to long-wave. Viewed with the desk-model spectroscope, the sample displayed two closely spaced bands in the green region. This absorption pattern is associated with some red dyed quartz, supporting the

Figure 31. This 14.32 ct alabaster cabochon proved to be dyed; note its resemblance to opal or chalcedony. Also note the whitish chipped areas on the dome due to its very low hardness. Photo by G. Choudhary.

possibility that the alabaster was dyed. With magnification, the stone clearly exhibited concentrations of red and pink in surface-reaching fractures (figure 32). Color variations also were observed in the form of curved bands, with darker zones of concentrated dye in some areas and portions of the original white bodycolor clearly visible in others (again, see figure 32).

The sample's FTIR spectrum displayed complete absorption up to ~5300 cm^{-1}, and bands from 5800 to 5400 cm^{-1} and 6700 to 6300 cm^{-1}. This pattern resembled that of a colorless gypsum in our database, and it is commonly associated with other hydrous minerals. The complete absorption of wavelengths in the 3200–2700 cm^{-1} region precluded the detection of any absorption features related

Figure 32. Surface-reaching cracks in the dyed alabaster displayed concentrations of red and pink. See also the curved color banding on the lower left. Photomicrograph by G. Choudhary; magnified 10×.

to organic dyes or other substances such as wax. Qualitative EDXRF analyses revealed the expected S and Ca, and traces of Sr, but no elements related to a coloring agent were detected.

Dyed gypsum was mentioned in the Summer 1963 issue of *G&G* (R. Crowningshield, "Developments and Highlights at the Gem Trade Lab in New York," p. 44) and in the Fall 1964 *G&G* (R. T. Liddicoat, "Developments and Highlights at the Gem Trade Lab in Los Angeles," p. 219); the latter report stated "A group of pieces of inexpensive antique jewelry contained green and pink colored beads that proved to be dyed-and-heavily-waxed alabaster." Although the luster of the present cabochon also suggested that wax had been applied in addition to dye, there was no evidence of wax seen when the sample was scratched, and hot point testing was not performed.

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CONFERENCE REPORTS

31st International Gemmological Conference. Approximately 70 delegates, observers, and guests participated in this meeting October 8–14, in Arusha, Tanzania. Some of the presentations are summarized here.

George Bosshart (Horgen, Switzerland) reported on the use of new 3D visualization methods in the transition from open-pit to underground mining at the Argyle diamond mine, which will extend its life beyond 2018. **Thomas Hainschwang** (Gemlab Laboratory, Balzers, Lichtenstein) compared near-colorless type Ia and IIa diamonds irradiated by neutrons or electrons, before and after annealing. The brown color in irradiated/annealed diamond is caused by a stable defect consisting only of vacancies, possibly similar to the vacancy cluster that is likely responsible for brown color in untreated diamond. Dr. **Yuri Shelementiev** (Moscow State University [MSU] Gemmological Center, Moscow) presented a hardware and software package for the objective grading of polished diamonds. He demonstrated the Helium Polish scanner for obtaining precise three-dimensional diamond models, the use of DiamCalc software for grading color and cut, and the M-Box system with Oxygen software for mapping inclusions. **Maxim Viktorov** (MSU Gemmological Center) advocated applying 3D modeling and computer analysis to improve existing classification systems of rough diamond. **Dr. Joe Yuan** (Sun Yat-sen University, Guangzhou, China) predicted that we will soon see hybrid natural/synthetic CVD diamond, produced by growing a layer of CVD material over the sawn face of a natural diamond.

Dr. Walter Balmer (Department of Geology, Chulalongkorn University, Bangkok) reported on the geology of marble-hosted ruby deposits from Morogoro, Tanzania. Their mineral inclusions resemble features in rubies from Mogok (Myanmar) and Luc Yen (Vietnam).

Thanong Leelawatanasuk (Gem and Jewelry Institute of Thailand, Bangkok) presented data on natural and heat-treated rubies from a new occurrence in Mozambique (exact locality not specified). The chemical composition appears similar to that of Winza (Tanzania) rubies, but the stones contain locality-specific internal features, such as lamellar twins and intersecting growth tubes. **Dr. Dietmar Schwarz** (Gübelin Gem Lab, Lucerne, Switzerland) compared properties of emeralds from Southeast Asia and China with those from Colombia; though Chinese emeralds may show three-phase inclusions, their UV-Vis spectra are distinctly different due to the presence of Fe^{2+}. **Julien Feneyrol** (CRPG, Nancy-Université, France) described the geology and chemical composition of tsavorite from Lemshuku/Komolo and Namalulu, Tanzania, where the garnet crystallized in veins associated with altered graphitic gneisses near dolomitic marbles. **Dr. Xin-Qiang Yuan** (Gemological Institute of China University of Geosciences, Wuhan) reported on his research into the separation of untreated from irradiated blue topaz by cathodoluminescence, using colorless topaz as a reference.

Dr. Emmanuel Fritsch (University of Nantes, France) described causes of luminescence in opal. Blue luminescence is due to the combined emission of two centers, at 414 and 465 nm; green is seen when the uranium concentration exceeds 1 ppm. Luminescence is quenched by iron; no luminescence is observed when Fe exceeds 2000 ppm. **E. Gamini Zoysa** (Institute of Gemmological Sciences, Colombo, Sri Lanka) described white opal recently found in alluvial gravels in Balangoda, Sri Lanka. **Dr. Margherita Superchi** described bright yellow danburite, recovered in 2007–2008 from central Madagascar. The properties of this material are very similar to those of yellow danburite from Tanzania. **Tay Thye Sun** (Far East Gemological Lab, Singapore) presented data on yellow beryl sold in Hanoi and Ho Chi Minh City, which is suspected to have been irradiated.

Dr. Stefanos Karampelas (Gübelin Gemmological Laboratory, Lucerne, Switzerland) demonstrated the use of Raman spectroscopy to identify various mollusks associated with natural and cultured pearls according to characteristics of their pigments (both natural and treated color). **Dr. Michael Krzemnicki** (SSEF Swiss Gemmological Institute, Basel) reported on the use of X-ray micro-tomography to identify beadless cultured pearls. **This contributor** reported on a large pearl of 2,385 grains, which was purchased at auction in Amsterdam in 1778 and has been locked away in a Dutch private collection for most of the time since then.

Post-conference field trips were organized to the Williamson diamond mine, TanzaniteOne's operation at Merelani Block C, the Lake Manyara emerald/alexandrite deposit (figure 33), and the Longido ruby-zoisite mine.

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Figure 33. IGC paticipants toured this emerald and alexandrite mine near Lake Manyara in Tanzania. Photo by Vincent Pardieu.

2009 NAG Institute of Registered Valuers' Conference. This two-and-a-half-day conference, held September 19–21 by the National Association of Goldsmiths at the Loughborough University of Technology in England, was attended by 160 participants. Now in its 21st year, the annual event covers many aspects of gemstone and jewelry appraisal through a combination of presentations, panel discussions, and workshop sessions. This year's theme was color, with many of the presentations focusing on various aspects of colored stones, particularly color communication, identification, grading, and appraising.

A number of the workshops involved a combination of lectures and hands-on practical lab time with stones, reference materials, and tools. In addition, Dr. Sally Baggott and Craig O'Donnell (Birmingham Assay Office) conducted a session on famed silversmith Matthew Boulton, providing numerous examples of his work and highlighting his involvement in the establishment of the Birmingham Assay Office, which was founded in 1773. This year marks the bicentennial of Mr. Boulton's death. Another presentation was given by David Thomas, who was England's Crown Jeweller from 1991 to 2007. Mr. Thomas described what the position meant to him, how he attained it, and his role in ceremonial occasions. The talk was illustrated with images of some of the priceless pieces in the Royal Collection.

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ERRATUM

In table 1 of the Fall 2009 GNI entry on triphylite (pp. 229–230), the major-element contents measured by LA-ICP-MS were reported incorrectly (i.e., for P, Li, Fe, and Mn). We thank Dr. Karl Schmetzer for bringing this to our attention.

LETTERS/BOOK REVIEWS/GEMOLOGICAL ABSTRACTS
2009 ANNUAL INDEX

The *Gems & Gemology* Letters, Books Reviews, Gemological Abstracts sections, and the 2009 Subject and Author Index are available only in electronic (PDF) format. These sections are available free of charge both on the *G&G* web site (www.gia.edu/gemsandgemology) and as part of *G&G* Online (gia.metapress.com), and are paginated separately from the rest of the issue.

These sections are also included in this full-issue PDF. Accordingly, the Table of Contents included in this file lists these additional sections, and thus differs from the Table of Contents in the print version. For these reasons, this PDF is not the official version of this issue—the "journal of record" for this issue is the combined print/online version that was released to subscribers.

MORE ON GREEN AMBER

I am delighted that a comprehensive paper has been published about the effects of the treatment performed on various ambers and copals to turn them green (A. Abduriyim et al., "Characterization of 'green amber' with infrared and nuclear magnetic resonance spectroscopy," Fall *G&G*, pp. 158–177). The tests conducted by the authors were extensive and thorough, but it appears that only the outer surface of the resins altered by treatment was tested. None of the samples was cut in half to see what had happened to the interior.

Awhile back I had some pieces of treated Colombian copal tested in London, and the inside of the material gave a different FTIR reading from the outer surface, indicating that the treatment did not penetrate all the way through.

I have long maintained that, no matter what treatment it is subjected to, the immature resin copal should not be referred to as *amber*. The fact that this treated copal may not have hardened all the way through means that the center is still copal, even if the outer surface resembles some kind of amber in appearance and in testing.

I am worried the Laboratory Manual Harmonization Committee (LMHC) has now decided that a sample should be called *amber* when it is not possible to determine by testing exactly which resin has been used as a starting material—albeit with the addition of some words to say that it shows signs of treatment and may be derived from copal.

Some of the green material on the market today derives from amber, but much of it uses Colombian copal as the starting material. I feel that we degrade true amber by using the word *amber* for material that may well be copal.

In my experience, the general public is already afraid to buy amber because they have heard that much of it is treated or even faked. Surely, by accepting that we can call copal *amber*, we risk damaging this shaky reputation even further?

Maggie Campbell Pedersen
Editor, Organic Gems

Reply

I appreciate Ms. Campbell Pedersen's comments, and welcome the opportunity to clarify some items. First, in this study, Fourier transform infrared spectroscopy (FTIR) and nuclear magnetic resonance (NMR) were used to study the bulk structure of several green amber samples, both on the surface and in the interior. The FTIR spectra of the surface and internal sections of "green amber" created from Brazilian and Colombian copal presented similar features. However, there is a possibility that some commercial treated "green amber" may show spectral features of copal due to insufficient treatment or an incorrect approach being applied in the heating process; this material should therefore be described as *copal*.

Second, there appears to be a misunderstanding about LMHC nomenclature for "green amber." LHMC members will not call all green or even yellow-brown resins *amber* without an accurate analysis. If the presence of the Baltic shoulder and 820 cm^{-1} absorption features in the FTIR spectrum of green and yellow-brown treated material is confirmed, the material should be called *amber* and the following comment placed on the report: "Indication of heating, this resin has been processed by heat and pressure."

If the material lacks the Baltic shoulder but shows amber-like absorptions, and it is extremely difficult to identify the starting resin, the item should be called *amber* but only after a full analysis of the surface and/or interior (if permitted by the client). The statement "Indications of heating, this resin has been processed by heat and pressure and may have been derived from copal" would then be placed in the comments.

Further, the LMHC position on this material is still being finalized. If the interior of the sample gives an FTIR reading different from that of the outer surface—that is, the outer surface resembles some kind of amber and the center is still copal—it should be called *copal* only. The LMHC is presently considering the scenario where permission is not given to cut a sample of green amber in half, and will discuss whether a comment such as "Green amber is commonly derived from copal material" should be added to reports.

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Editors

Susan B. Johnson
Jana E. Miyahira-Smith
Thomas W. Overton

Emeralds: A Passionate Guide: The Emeralds, the People, Their Secrets

By Ronald Ringsrud, 382 pp., illus., Green View Press [www.emerald-passion.com], Oxnard, CA, 2009. $80.00

This is a personal account of the world of emeralds from the perspective of a renowned connoisseur. It offers an in-depth look at the life of a Colombian emerald dealer, illustrated with many personal adventures, experiences, observations, and opinions. Colorfully and tastefully illustrated, the book shows many superb examples of beautiful and unusual emeralds. Indeed, it is an unabashed celebration of colored gemstones, emerald in particular.

As the author states in the introduction, "This book is about passion, not polarizers." Comprising 23 chapters, it starts straightaway with how romance can influence deals between sellers and buyers, with an interesting explanation for the differences in behavior between a dealer and a broker. Subsequently, it details the discovery and ascendancy of the Colombian emerald mines under Spanish rule, roughly between 1500 and 1750. As a Dutchman, I learned how my ancestors used "well-placed bribes" to acquire emeralds during that period.

Subsequent chapters discuss the properties and optics of emeralds, color and clarity grading, and clarity enhancement. The author emphasizes the subtle differences in color and clarity, and the positive effect inclusions

may have. He expresses concern that emerald enhancements and their durability are discussed too much, often increasing confusion and fear. He emphasizes that size, quantity, and position of filled fissures are most important—not the type of filler—when assessing durability issues and degree of clarity enhancement.

Interestingly, *gem laboratory* is synonymous with *ivory tower* throughout this book, revealing the difference between an academic approach (which the author criticizes) and that of the connoisseur. He agrees it is important to know how to use the information on a gem report, but he maintains that in the trade there is also a need for documentation that gives some background information to evoke the wonder and reverence that fine gems deserve.

The book gives a clear explanation of what is meant by the term *gota de aceite*, which is not simply a catch-all superlative for a fine Colombian emerald, as often misapplied in Europe and the United States. Also clarified is the proper use of *old mine*, and the difference between that term and *gota de aceite*.

The reader is brought up to date with current Colombian emerald production, which still matches the quality of the beautiful antique emeralds the Spanish conquerors sent to Europe and India. The author explains that money spent on Colombian emeralds does not support narcotics trafficking and also discusses examples of fair trade initiatives that benefit the local miners.

The basics of emerald geology are

introduced in a loose, informal way. The author rightly emphasizes the importance of Terri Ottaway's geologic work, which marked a shift in thought about the formation of emerald in Colombia. Strangely enough, only her master's thesis is mentioned, not the landmark paper she and her colleagues published in *Nature*. Nor does the author refer to the similar formation theory proposed in articles by Giuliani, Cheilletz, and co-workers, which produced additional valuable data and insights.

This book is especially outstanding for its many interesting personal anecdotes. Among them is a witty, recognizable account of working in the field—with interaction between the investor, the geologist, the foreman, and the miners. It further includes a personal account on the business of buying and cutting rough emeralds, with a memorable story of missing a buy. A fairly expansive section on cutting emeralds explains the process, with revealing insight into the prices involved and what is at stake for the owner *and* the cutter. The author expresses his view on colored stone grading systems, contending that colored stones should be sold one by one, like works of art.

In the chapter on collecting mineral specimens, the author demonstrates his true love for emeralds. He describes parting with a nicely terminated crystal, rightly sold as a specimen rather than a faceted gem, only

to see it end up as an inelegant 14 ct emerald-cut piece that had lost much of its color.

Still, the strength of this book can be a weakness at times. Because "there is no distance between the author and emeralds," in the author's words, facts and opinions are often intermingled. For instance, the statement that the color of tsavorite is always steely and too brilliant is purely subjective—a matter of taste. Other statements need a clear reference, such as the assertion that 70% of the emeralds of the world by volume and 30% by value are cut, polished, and marketed in Jaipur (which is inconsistent with other published data). The book also contains some small errors and omissions. The stated refractive indices of quartz (1.559–1.568) are too high (they are typically 1.544–1.553), and emeralds from Colombia show a wider range of RIs than indicated. The author describes glass doublets as imitations of emerald, but does not mention rock crystal doublets or the deceptive beryl doublets. The discussion of clarity grading is also unclear at times.

Aside from these criticisms, this book is a must for anyone who loves colored gemstones and wants to know more about the world of emeralds. In particular, it is highly recommended to gemology students as it will help put into broader perspective and context what they learn in the classroom.

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The French Blue

By Richard W. Wise, 489 pp., illus., publ. by Brunswick House Press [www.thefrenchblue.com], Lenox, MA. $29.95.

This is a fascinating account of both fictional and factual events surrounding the six voyages that Jean Baptiste Tavernier made to India from 1631 to 1669. The story starts with Tavernier's early life and his introduction and apprenticeship into the jewelry industry. It then focuses on his dealings in gems, with emphasis on the trade routes, mining procedures, and business practices of the period that Tavernier wrote about and his fictional quest for "the one stone" that would set him up for life: the diamond that would one day be known as the French Blue. The author began with Tavernier's famous memoir and researched other historical documents to weave a fascinating tale of adventure and global intrigue. Those who wonder what life was like during the mid-17th century will find the fictional scenarios quite plausible, delivered in an entertaining, easy-to-read manner.

Although the cover states that the book is based on a true story, it would be impossible for the casual reader to separate fact from fiction. The epilogue notes that several chapters and characters were created to fill in the years that Tavernier omitted in his writings. Other details and events scattered throughout the book are also clearly fictionalized, particularly some rather descriptive sexual trysts.

In addition, one would have to be familiar with the history of the French Blue diamond to see the correlation between the title and the story. The slab-cut diamond Tavernier purchased in India and sold to France's King Louis XIV has been known as the *Tavernier Blue* since the late 1800s. In 1671, it was recut into the *Diamant Bleu de la Couronne*, or *Blue Diamond of the Crown*, which also was not known as the *French Blue* until the late 19th century—long after it, too, had been recut, to become the Hope diamond. Unfortunately, the author uses each of the terms *Tavernier Blue* and *French Blue* only once, while the diamond is referred to many times in the last two chapters as either "the Blue" or "the Great Blue." This is likely to be confusing to anyone unfamiliar with Tavernier's writings.

The blurring of fact and fiction precludes this book from being considered an authoritative reference, although it does provide plausible insights into gemstone and diamond trade practices, trading routes, and the challenges Tavernier encountered. The French Blue is recommended for those interested in a well-written, entertaining story surrounding a singular figure in the history of diamonds.

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The Pearl Oyster

Edited by Paul C. Southgate and John C. Lucas, 582 pp., illus., publ. by Elsevier [www.elsevier.com], Amsterdam, The Netherlands, 2008. 91.95 (US$111.00)

"The shell is prosocline, inequilateral, typically rounded to anteriorly obliquely ovate in outline. The umbones are subterminal, located posterior to the anterior auricles, and slightly projected beyond the straight hinge, with the umbo in the left valve elevated slightly more dorsally than the umbo in the right valve." As the preceding sentences attest, *The Pearl Oyster* is written and edited largely by and for academics and others with a background in mollusk science. However, the book also has great value for lay readers, especially if they can get up to speed with the vocabulary of mollusk biology.

In 16 chapters written by 26 credited contributors, the editors have compiled a wealth of information previously available only in hundreds of academic journal articles and other documents. Nearly every chapter has an extensive list of references at its end, giving each at least the appearance of authority and accuracy. Chapters 2 ("Taxonomy and Phylogeny") and 5 ("Reproduction, Development and Growth") are each followed by nine pages of references listed in 8-point type.

It's disturbing, then, that a somewhat knowledgeable reviewer easily finds factual, typographic, style, and usage errors. Unfortunately, their

presence detracts from the authority of the book. Perhaps if Messrs. Southgate and Lucas, who are academic marine biologists and not editors *per se*, had enlisted help from a professional editor, the errors could have been caught and corrected.

Each chapter begins with an introduction and ends with a summary, which is a blessing, especially for lay readers. In Chapter 8 ("Pearl Production"), Joseph Taylor, a PhD marine biologist and, until recently, the hands-on managing director of Atlas South Sea Pearl, and Elisabeth Strack, author of the monumental *Pearls* (reviewed in *G&G*, Spring 2007), give an excellent account of pearl formation. In text worthy of applause, the chapter debunks the oft-repeated notion that natural pearls form around an irritant lodged in a pearl-bearing mollusk's tissue.

In Chapter 13 ("Economics of Pearl Farming"), Clem Tisdell, an economist at the University of Queensland, and Bernard Poirine, of the University of French Polynesia, make a gallant effort to analyze and explain the topic. Their sentence, "It is very difficult to obtain accurate global statistics for pearl production and sales" is revealing. This reviewer knows from extensive personal experience that "impossible" would have been a better descriptor.

Although *The Pearl Oyster* is nearly exclusively about saltwater pearling—Chinese freshwater cultured pearls, which annually outweigh saltwater cultured pearls by a factor of about 13, are barely mentioned—and although much of the information has little or no practical application, the book is a worthwhile addition to any serious pearler's library.

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Collector's Guide to Fluorite

By Arvid Eric Pasto, 96 pp., illus., publ. by Schiffer Publishing [www.schifferbooks.com], Atglen, PA, 2009. $19.99

Fluorite, one of the three most popular collector minerals, is certainly deserving of a book covering the many aspects of its appeal—aspects realized in this *Collector's Guide*. The author has been a mineral collector since the 1950s, and nearly all the specimens depicted are from his collection. Their quality and variety demonstrate his keen knowledge and good taste in fluorite specimens.

The introduction includes a discussion of fluorite's composition, uses—including, very briefly, as a gemstone—color, and fluorescence, with a bit about its history. In the next section, "Structure and Crystallography," fluorite's crystal form is detailed down to the unit cell, with understandable text and clear, colorful graphics. Its crystallography and many forms and combinations thereof are well addressed and illustrated. Photographs that clearly display these forms will assist collectors in identifying them in their own specimens. "Physical Properties" describes cleavage, hardness, and specific gravity, among others, and even touches on such topics as radioactivity, magnetism, and electrical and thermal properties. The "Optical Properties" section features a table on fluorite's colors and their causes, and another on its fluorescence colors. Other factors of interest such as mineral associations, phantom growths, pseudomorphism, and inclusions are covered next. This is followed by a section devoted to formation that describes four types of economically important ore deposits and the five major types of physiochemical environments in which they can occur.

Last, and perhaps most interesting, is the section on classic fluorite localities. The best-known sources are broken down by continent, country, and region. Very good color photographs taken by the author accompany these descriptions. The specimen selection and the quality of the images should prove valuable to all levels of collectors as an aid in distinguishing a specimen's origin. Rounding out the book is a bibliography with a wealth of references.

Collector's Guide to Fluorite is an excellent resource for this highly collectible species and should be of great value to mineral collectors at all levels. For the gemologist, there is plenty of useful data on its properties, structure, history, and even inclusions, though the book includes little on fluorite as a fashioned gemstone. Despite this, one would still hope that lapidaries and gemologists will appreciate the natural beauty of fluorite and gain much from this work.

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OTHER BOOKS RECEIVED

The Bohemian Crown Jewels. By Andrej Šumbera, transl. by Zuzana Jurgens, 114 pp., illus., publ. by the author [http://korunovacni-klenoty.cz], 2008, 20.

This pocket-sized work is a photographic catalogue of the Crown Jewels of the Kingdom of Bohemia, which date from the reign of King Charles IV (1316–1378). The book is the product of gemological examinations conducted in 1998 and 2003; a review of these examinations is also provided. Included is a CD-ROM with 600 additional photos.

TWO

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O9 GEMOLOGICAL Abstracts

COLORED STONES AND ORGANIC MATERIALS

Chemical signatures of fossilized resins and recent plant exudates. J. B. Lambert, J. A. Santiago-Blay, and K. B. Anderson [kanderson@geo.siu.edu], *Angewandte Chemie International Edition*, Vol. 47, No. 50, 2008, pp. 9608–9616.

Amber is the hardened fossil form of viscous, sticky resins secreted by certain plants. An investigation of ambers from various geographic sources using modern analytical techniques has provided structural information that can be used to classify this material and help identify the ancient plants that produced the resins. Using mass spectrometric analysis of components separated by gas chromatography, the authors propose a five-category classification scheme for fossil resins based on the presence of specific organic compounds. This scheme is supported by nuclear magnetic resonance spectroscopy of different kinds of fossil and modern resins. The article concludes with a discussion of the analytical challenges of identifying the ancient plant species responsible for the various types of amber. *JES*

Common gem opal: An investigation of micro- and nanostructure. E. Gaillou [gailloue@si.edu], E. Fritsch, B. Aguilar-Reyes, B. Rondeau, J. Post, A. Barreau, and M. Ostroumov, *American Mineralogist*, Vol. 93, No. 11/12, 2008, pp. 1865–1873.

The microstructure of nearly 200 samples of common gem opal obtained from localities worldwide was investigated using scanning electron microscopy (SEM). Although lacking play-of-color, these common opals can have gem value because of their bodycolor. As seen in SEM images, opal-CT (disordered cristobalite/tridymite structure) and most opal-A (amorphous struc-

ture) consist of arrangements of nanograins that average about 25 nm in diameter. In most opal-A samples, the nanograins are arranged into spheres that have concentric layers or, in some cases, radial structures. The spheres are cemented together by silica that fills the voids between them; in some cases, the spheres themselves are distorted in shape by compaction of the material. The authors suggest several reasons why these opals do not display play-of-color, including spheres that are of different sizes, are imperfectly shaped, are too large or too small to diffract light, or are not well ordered in their packing arrangements. In contrast, opal-CT samples display different degrees of nanograin ordering from none (random aggregation of nanograins) to fibers, flat platelets, and even more complex arrangements called lepispheres (sphere-like aggregates of platelets). The degree of nanograin ordering may depend on the growth or deposition rate imposed by the properties of the silica gel from which the opal settled. This rate is presumably faster for opal-CT and slower for opal-A. *JES*

Economic analysis of land-based production of cultured marine pearls in India. G. Syda Rao [gsydarao@gmail.com] and R. N. Kumar, *Aquaculture Economics & Management*, No. 12, 2008, pp. 130–144.
This article analyzes a decade-long project in the Indian city of Visakhapatnam (Andhra Pradesh) to produce cultured akoya pearls in land-based saltwater tanks instead of ocean farms. The rationale for cultivating pearls on land is that the mollusks are shielded from predators, parasites, and violent weather. It also reduces the need for costly cleaning and maintenance.

The project used oysters that were raised in hatcheries and algae feed that was cultivated in special tanks. Cultured pearl production took between 12 and 18 months. An average of 60% of the crop was 6 mm in diameter, while 25% reached 7 mm, and 15% was 8 mm. The overall yield was 25%, and the cultured pearls were grouped into three quality categories: A (25%), B (50%), and C (25%). While 70% of the oysters rejected the nuclei in the first seeding, the land-based production process made it easy to retrieve the rejected nuclei and reseed the oysters after a "convalescing" period.

The study concluded that land cultivation could be profitable, noting that yearly operating income averaged $159,197 over the 10-year project. *RS*

Garnet. H. A. Gilg, D. Kile, S. Liebetrau, P. Modreski, G. Neumeier, and G. Stabler, Eds., *extraLapis English*, No. 9, 2008, 98 pp.
Like previous editions in the series, this is an English-language version of the German *extraLapis*. The discussion begins with a review of garnet chemistry and the known members of the garnet group. This is followed by a series of chapters describing the species most popular as gem materials—almandine, andradite, grossular, pyrope, and spessar-

tine—and the major localities in which they are found (uvarovite is also discussed briefly). The issue concludes with a review of garnet's use as an industrial material, synthetic garnets (mainly YAG), and garnet inclusions. *TWO*

Rare ivories. G. Brown, *Australian Gemmologist*, Vol. 23, No. 11a, 2009, pp. 1–47.
This article was initially a presentation that was scheduled to be delivered by gemologist Grahame Brown in Hobart, Tasmania, at the 2007 Gemological Association of Australia Annual Federal Conference. Although Dr. Brown was unable to attend, gemologist Hylda Bracewell presented the lecture.

"Rare ivories" are "products of manufacturing non-elephantine tooth and/or bone" for jewelry and other decorative purposes. Such ivory and ivory-like materials include mammoth ivory, elephantine molar teeth, elephant "pearls," odontolite, sperm whale ivory, walrus ivory, hippopotamus ivory, narwhal ivory, warthog ivory, circled boar tusks, dugong tusks, crocodile teeth, tiger canine teeth, bear teeth, elk teeth, oosik (walrus penile bone), Steller's sea cow bone, and bony antler. Each material is copiously illustrated with identifying features, carved samples, and cross-sections.

Some of the information provided is both enlightening and confusing at the same time. In the section on the coloration of odontolite, the popular belief for years has been that the unusual and attractive blue color is caused by prolonged burial of fossil ivory and development of the iron-phosphate mineral vivianite. Dr. Brown claimed that in fact Cistercian monks discovered a source of manganese-bearing fossil ivory in the Gers region of southern France and successfully mimicked the blue coloring by heating the material in oxygen in excess of 600°C for eight hours to produce a convincing substitute. What remains unclear is whether the author believed that all odontolite is produced in this manner. *JEC*

DIAMONDS

Blue fluorescence in diamonds. G. Holloway [garryh@ideal-scope.com], *Australian Gemmologist*, Vol. 23, No. 1, 2009, pp. 408–414.
This article reviews the relationship between diamond fluorescence and transparency and color appearance. Top-color (D to F on the GIA color grading scale) fluorescent diamonds, historically known as "blue white," were once priced around 10% higher than nonfluorescent diamonds. In 1993, a Korean TV exposé accused local laboratories of overgrading the color of fluorescent diamonds; the apparent result was an adjustment in the *Rapaport Diamond Report* price guide. Top-color fluorescent diamonds were discounted, and those with a color grade lower than I were subject to a premium; the author finds this contradictory.

GIA's studies on diamonds and their fluorescence indicate a perceptible relationship between blue fluorescence and color appearance, depending on the viewing position. On average, strongly fluorescent diamonds were found to have a better color appearance face-up, but the strength of fluorescence had no perceptible effect when they were viewed table-down (as is typical in laboratory and trade grading). Another conclusion was that very strongly fluorescent diamonds set in jewelry are no less transparent.

The author recommends the use of digital or instrument-based color grading, in the face-up position, using perhaps half the radiation strength of long-wave UV light (as found in shaded daylight). If industry standard-setting bodies could agree on an appropriate light source for face-up color grading, there would be no need to price fluorescent diamonds differently. *GL*

Morphology of diamonds from kimberlite pipes of the Catoca field, Angola. V. N. Zinchenko [vladimir.zin@mail.ru], *Geology of Ore Deposits*, Vol. 50, No. 8, 2008, pp. 806–814.

The Catoca diamond field is located in Lunda Province of northeastern Angola. The author provides morphological data for more than 3,200 diamond crystals from several kimberlite pipes in this field (including Catoca, Kamitongo, and Kakele). More than 75% of the crystals measured <1.5 mm, with the remainder ranging up to ~5 mm. Crystal shape, surface quality, evidence of etching or intergrowths, presence of inclusions, color, and transparency are summarized. Although the crystals from these deposits exhibited an overall similarity in their features, suggesting some commonality in geologic origin, they also displayed some characteristics unique to particular pipes. Studies of diamond crystals from other deposits around the world have provided some general guidelines on using crystal morphology and quality to predict the gem diamond potential of kimberlite pipes in the preliminary stages of mining. *JES*

Spectroscopic methods for the identification of natural yellow gem-quality diamonds. L. Tretriakova [ltret@gemfacts.com], *European Journal of Mineralogy*, Vol. 21, No. 1, 2009, pp. 43–50.

Characteristic spectroscopic features and identification criteria are presented for various types of yellow diamonds, including natural-color and artificially colored varieties. Infrared, optical absorption, and laser-induced photoluminescence spectroscopy are discussed. The last technique is much more sensitive than optical absorption spectroscopy and can excite defects that have very low concentrations in diamonds. Examples are given of diamonds with high hydrogen content or with high nitrogen and low hydrogen. *RAH*

Unusual micro- and nano-inclusions in diamonds from the Juina area, Brazil. R. Wirth [wirth@gfz-potsdam.de], F. Kaminsky, S. Matsyuk, and A. Schreiber, *Earth and Planetary Science Letters*, Vol. 286, 2009, pp. 292–303.

Diamonds from the Juina area in Mato Grosso State, Brazil, are known for their unusual mineral inclusions, such as ferropericlase, that originated from very deep levels (i.e., the lower mantle at >660 km). In this research, three diamonds from Rio Soriso in the Juina area were studied using transmission electron microscopy, analytical electron microscopy, and nanoSIMS analysis.

The diamonds contained micro-inclusions (1–300 μm) that formed as mineral assemblages. A dolomite crystal (2.5 × 1.5 μm) was found associated with ilmenite and graphite. Calcite was detected as 1–2 μm polycrystalline grains, together with wollastonite-II (a dense polymorph of wollastonite), cuspidine, and monticellite. The grain size of wollastonite-II reached several microns. Cuspidine was intergrown with wollastonite-II, possibly when it replaced wollastonite-II in the presence of a fluorine-rich fluid. Coesite grains were lath-shaped and 50–100 nm in size; they formed polycrystalline aggregates containing pores up to several hundred nanometers filled with nano-inclusions (<200 nm) of halide ($NaCl$, $CaCl_2$, KCl, and $PbCl_2$), TiO_2, and anhydrite. Other nano-inclusions such as ilmenite, spinel, and phlogopite were also identified. Sulfide micro-inclusions formed as individual plate-like features. Three of the micro-inclusions—cuspidine, monticellite, and anhydrite—were discovered for the first time as inclusions in diamond.

All the micro- and nano-inclusions were of eclogitic origin. These Juina diamonds may have formed from the subduction of crustal material to a deeper level of the lower transition zone or the lower mantle. The upper limit of formation pressure for these diamonds may exceed 10 GPa. The unique micro-inclusion assemblage of calcite, cuspidine, wollastonite, monticellite, and fluid suggests that volatiles are important metasomatic agents in mantle processes, particularly in diamond formation. *KSM*

GEM LOCALITIES

Chemical variations in multicolored "Paraíba"-type tourmalines from Brazil and Mozambique: Implications for origin and authenticity determination. A. Peretti [adolf@peretti.ch], W. P. Bieri, E. Reusser, K. Hametner, and D. Günther, *Contributions to Gemology*, No. 9, 2009, pp. 1–77, www.gemresearch.ch/journal/No9.

This edition of *Contributions to Gemology* presents a detailed characterization of a suite of Cu-bearing tourmalines from localities in Brazil (Paraíba and Rio Grande do Norte States) and Mozambique (Nampula Province). Such

material also comes from Nigeria (Idaban and Ilorin). When present with other coloring agents (particularly Mn, Fe, and Ti in varying proportions), Cu contributes to a wide range of sometimes bright colors in elbaite tourmaline: blue, violet, purple, purple-red, and green. Heat treatment is commonly used to improve the color of Cu-bearing tourmalines.

This study focused on the quantitative chemical analysis of color-zoned tourmalines using several techniques to identify their important minor and trace elements, and to map the spatial distribution of these elements in relation to the crystal structure and the arrangement of color zones. The methods included electron microprobe analysis, energy-dispersive X-ray fluorescence (EDXRF) spectroscopy, laser-induced breakdown spectroscopy (LIBS), and laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS). Most of the samples were crystal sections that had been cut perpendicular to the c-axis to reveal the internal arrangement of concentric color zones. Numerous graphs correlate changes in composition across the color zones in these sections. The report concludes with a number of two- and three-dimensional plots of chemical composition data for various bodycolors that illustrate how certain elements (such as Cu, Mn, Zn, Pb, Bi, and Ga) or element-pair comparisons provide a means of determining the geographic source of Cu-bearing tourmaline. There is also a brief description of some of the inclusions and growth features seen in bluish green tourmalines from Mozambique.

JES

Edle Zirkone aus dem Sächsischen Vogtland [Gemmy zircons from Vogtland, Saxony]. W. Modaleck, G. Seifert, S. Weiss, U. Lehmann, S. Kreher, and K. Thalheim, *Lapis*, Vol. 34, No. 2, 2009, pp. 13–26, 54; **Edelstein-Zirkone aus Goldseifen im Göltzschtal, Sachsen [Gem zircons from gold placers in Göltzschtal, Sachsen].** J. Leichsenring, *Lapis*, Vol. 34, No. 2, 2009, pp. 27–28; and **Hyazinthe und "Malakone" im Ofen: Zur Farbursache und Fluoreszenz sächsisch/bayerischer Zirkone [Hyacinths and "malakones" in the furnace: On the origin of color and fluorescence of Saxonian/Bavarian zircons].** S. Weiss, S. Meier, and R. Duthaler, *Lapis*, Vol. 34, No. 2, 2009, pp. 37–40 [all articles in German].

Generally, Europe is not rich in gem deposits. These three articles describe the occurrence of gem-quality zircons in Germany's Saxony region. Modaleck et al. report that zircons were first mentioned in 1710 as "little stones [*Steinlein*] similar to diamonds" that were found in gold placers in Göltzschtal (Göltzsch Valley), Saxony. In 1994 these zircons were rediscovered by local rockhounds, and in 1998 the first "Göltzsch brilliant" was cut. Three types of zircons can be distinguished: transparent pastel yellow ("jargon"), transparent dark purplish red ("hyacinth"), and

almost opaque in typically green hues ("malakon"). In 2005, prospecting revealed that a maar volcano near Ebersbrunn was the source of the Göltzsch zircons. Similar zircons can be found elsewhere in Saxony as well as in other Tertiary volcanic areas in Europe (e.g., Laacher See, Eifel Mountains, Germany and Espaly/Le Puy, Massif Central, France). Leichsenring describes the activities of local "diggers" and the actual possibilities of finding zircon, gold, and other minerals, while Weiss et al. conducted heating experiments. These experiments indicated that the colors of the Saxony zircons are due to color centers. Heating caused "jargons" to lose their coloration, while "hyacinths" and brown "malakons" acquired an additional orangy red hue. After heating to more than 500°C, UV fluorescence disappeared. All these phenomena can be linked to the presence of radioactive trace elements in the zircons, especially Th, U, and Nb. A comparison with green zircons and the "original" black "malakons" from Sri Lanka showed that the latter contained much more Th than was found in those from Saxony. *RT*

Gemstone and mineral mining in Pakistan's mountains. J. Clanin, *InColor*, Spring 2008, pp. 19–25.

The Himalayan Mountains in northern Pakistan are geologically young but contain a wide variety of gems such as tourmaline, aquamarine, topaz, garnet, apatite, emerald, ruby, and sapphire. However, high elevations and harsh weather impose limits on the mining season. Most of the gem deposits are worked by small groups of miners using basic equipment that is hand carried or transported on horseback.

Marble-hosted ruby deposits are known at Ganesh, Gupa Nala, Dhorkan, and Hachinder in Hunza Valley. These marbles are part of the Baltit Group, a sequence of metasedimentary rocks. The host marbles generally contain phlogopite, margarite, muscovite, zircon, spinel, Mg-tourmaline, pyrite, rutile, and/or graphite. Another deposit was discovered recently near the village of Bisil in Basha Valley.

The Chumar Bakhoor pegmatites are located at an elevation of ~4,800 m and have produced aquamarine and fluorite. The Stak Nala pegmatites, which boast 40 mines, contain multicolored tourmaline. Hundreds of pegmatites are known along the Indus River, most of them on the sides of steep cliffs, and they have produced aquamarine, black tourmaline, topaz, apatite, and garnet from tunnels up to 150–180 m deep. Interestingly, global warming is helping to uncover potential new gem sites, as the Mani glacier has receded several miles in this area. Pegmatites in the Shigar, Braldu, and Basha Valleys are spread out over an area of 150 km^2, with no trails.

The lack of modern mining equipment, safety standards, and mining expertise is a major drawback for the miners in this mountainous region. Rockslides and falls are the leading causes of death, while the ~40,000 miners in Pakistan's mountains are also susceptible to silicosis

and carbon monoxide poisoning. Improving safety standards will take time, but there are a few measures that can be adopted immediately, such as wearing disposable dust masks and installing portable ventilation systems. Miners should also be trained in first-aid procedures and the use of mountain climbing gear. Finally, establishing community markets could bolster selling prices, thus benefiting both miners and the local residents.

KSM

"Multiphenomenal" quartz from India. G. Choudhary and M. B. Vyas, *Gems & Jewellery*, Vol. 18, No. 1, 2009, pp. 10–12.

An unusual 12+ ct quartz cabochon displaying both strong chatoyancy and a 10-rayed star set ~45° from the chatoyant band is described. Asteriated quartz typically comes from Sri Lanka, but this specimen is reportedly from the Indian state of Tamil Nadu. The stone had a bright medium yellow-green bodycolor, resembling cat's-eye chrysoberyl. Oriented needle-like inclusions created one set of rays intersecting at nearly 90° and another at ~60/120°; the chatoyant band was caused by very fine, densely packed flaky inclusions oriented parallel to the c-axis. The chatoyancy and asterism were confirmed as separate phenomena. EDXRF chemical analysis was inconclusive for identifying the inclusions. The results of gemological testing on the cabochon, including FTIR spectroscopy, were consistent with natural quartz. *ERB*

Mushroom elbaite from the Kat Chay mine, Momeik, near Mogok, Myanmar: II. Zoning and crystal growth. A. J. Lussier, F. C. Hawthorne [frank_hawthorne@ umanitoba.ca], S. Herwig, Y. Abdu, P. M. Aguiar, V. K. Michaelis, and S. Kroeker, *Mineralogical Magazine*, Vol. 72, No. 5, 2008, pp. 999–1010.

"Mushroom" tourmaline from the Kat Chay mine, Myanmar, has a black-to-gray single-crystal core that transitions into single-crystal prismatic colored/colorless tourmaline, which is overgrown by acicular subparallel crystals diverging toward the edge of the "cap." These acicular crystals are dominantly colorless to white, with a continuous black zone near the edge rimmed in pale pink. Electron microprobe results confirm that the crystal core at the base and the material near the top of the "mushroom" are elbaite, the principal substitutions being $Li + Al = 2 Fe$ and $B + Al = Si + Fe$. It is suggested that the changes in habit are driven in part by changes in external variables such as temperature and pressure, potentially accompanied by involvement of new fluid phases. *RAH*

Opal similarities between Andamooka and Coober Pedy, South Australia. I. J. Townsend [jackandjenny@ bigpond.com], *Australian Gemmologist*, Vol. 23, No. 1, 2009, pp. 415–420.

This paper examines the similarities of some of the opals from the Andamooka and Coober Pedy opal fields. The sedimentary host rocks at the two sites are similar, indicating that their geologic formation environments were also comparable. Because opals that form in similar rock types tend to resemble one another, some of the opals from Andamooka and Coober Pedy share many characteristics.

RAH

Ruby and sapphire from Marosely, Madagascar. L. Cartier [laurent.cartier@unibas.ch], *Journal of Gemmology*, Vol. 31, No. 5–8, 2009, pp. 171–179.

A detailed examination was performed on 35 partially polished rough, untreated corundum samples from a little-known eluvial deposit in south-central Madagascar. Colors ranged from purplish red to blue and were typically zoned, with an intermediate purple color overall. EDXRF spectroscopy revealed considerable variations, reflecting chemical intermediates between ruby and sapphire. The usefulness of FTIR spectra to detect heat treatment is discussed, especially the presence of 3309 and 3160 cm^{-1} peaks in natural, untreated corundum. The metamorphic Marosely corundums have been affected by metasomatism, making ultra–trace element analysis particularly relevant. LA-ICP-MS analyses of the chromophores in the color-zoned samples were consistent with the EDXRF data. The results for other trace elements (i.e., <1000 ppm) proved less revealing and underscored the need for further analyses, in combination with other methods, to advance corundum origin determination. *ERB*

Sapphire-ruby characteristics, west Pailin, Cambodia. F. L. Sutherland, G. Giuliani, A. E. Fallick, M. Garland, and G. Webb, *Australian Gemmologist*, Vol. 23, No. 1, 2009, pp. 401–406.

Trace-element and oxygen isotope analyses of Pailin sapphires and rubies further define the geochemical characteristics of this basalt-derived gem deposit, in which the corundum was transported to the surface as xenocrysts. The results confirm a clear distinction between sapphires of magmatic origin (2300–8000 ppm Fe, 15–1800 ppm Ti, 160–260 ppm Ga, <0.01 Cr/Ga, Cr below detection, and $\delta^{18}O$ 7.0–7.8‰) and those of metamorphic origin (3300–9130 ppm Fe, 60–3600 ppm Ti, 160–5300 ppm Cr, 28–46 ppm Ga, 3.6–155 Cr/Ga, and $\delta^{18}O$ 4.0–4.9‰). The Pailin magmatic suite was more depleted in Fe and had higher $\delta^{18}O$ values than the comparable bimodal gem corundum deposit at Barrington Tops (Australia), whereas the Pailin metamorphic suite was more enriched in Ti and Cr and distinctly lower in its $\delta^{18}O$ range. Thus, a geographic distinction can be drawn between the dual-origin corundum deposits that formed in these two regions, indicating differences in their geologic conditions during crystallization. These observations hold promise for "fingerprinting" individual corundum deposits. *RAH*

INSTRUMENTS AND TECHNIQUES

The application of confocal micro-Raman spectrometer to nondestructive identification of filled gemstones. J.-L. Fan [fanjianliang@mail.ecust.edu.cn], S.-G. Guo, and X.-L. Liu, *Spectroscopy Letters*, Vol. 42, 2009, pp. 129–135.

Filling is a treatment process in which a foreign substance is introduced into a stone's surface-reaching fractures to enhance its appearance and/or durability. Today, many varieties of filled gemstones are encountered in the market. When the fracture is extremely small or the filler concentration is low, it can be difficult to detect the treatment with basic gemological instruments. High-resolution confocal micro-Raman spectroscopy combined with microscopy provides a nondestructive, rapid, and accurate method for identifying these stones.

In this study, samples of bleached and filled jadeite and filled ruby were analyzed. Diagnostic Raman peaks near 3065, 2930, 1611, 1123, and 777 cm^{-1} proved that the jadeites were filled with an epoxy resin. In the rubies, a Raman peak near 1563 cm^{-1} was attributed to a lead glass, while the features near 3285, 2874, and 2331 cm^{-1} were associated with an organic filler. *GL*

Application of the Vis-NIR Avaspec-2048 portable automatic spectrometer to distinguish gem quality materials. D. Bernini, F. Caucia, and M. Boiocchi, *Neues Jahrbuch für Mineralogie, Abhandlungen*, Vol. 185, No. 3, 2009, pp. 281–288.

The use of the Avaspec-2048 portable fiber-optic spectrometer to analyze the Vis-NIR spectra of cut gemstones is described. For each sample, the spectrum was influenced by such factors as the stone's temperature, shape, carat weight, exposed surface area, and color. Efficient use of this instrument for discriminating gemstones will only be possible after a large and comprehensive reference database has been developed. *RAH*

Micro-Raman spectroscopy applied to the study of inclusions within sapphire. V. Palanza [palanza_valentina@yahoo.it], D. Di Martino, A. Paleari, G. Spinolo, and L. Prosperi, *Journal of Raman Spectroscopy*, Vol. 39, 2008, pp. 1007–1011.

The variety of inclusions observed in sapphires can be a function of geologic origin and, in some cases, is typical of specific deposits. The commercial value of sapphires is set by many factors, including origin. This study used micro-Raman spectroscopy to identify inclusions in 10 blue sapphires from Australia, Madagascar, Sri Lanka, Thailand, Tanzania, and Vietnam. The authors also used optical absorption spectroscopy to determine whether sapphires from these sources had a metamorphic or magmatic geologic origin. Taken together, these data allowed them to correlate inclusion varieties with both geographic and geologic origin. The addition of luminescence characteristics and chemical analyses from LA-ICP-MS would be expected to strengthen the conclusions about identifying gemstone origin. *ERB*

Use of laser induced breakdown spectroscopy in the determination of gem provenance: Beryls. C. E. McManus [katedowe@aol.com], N. J. McMillan, R. S. Harmon, R. C. Whitmore, F. C. De Lucia, and A. W. Miziolek, *Applied Optics*, Vol. 47, No. 31, 2008, pp. G72–G79.

The provenance of a gemstone is an important factor in its valuation, and one approach to identifying the geographic origin is to study inclusion assemblages. It is impossible to study every inclusion in detail, however, and the results may not be reliable. Gemstones form in various geologic environments and have unique chemical compositions. Therefore, studying the chemical composition of a gem, especially the trace elements, can provide the chemical fingerprint needed to identify its provenance. In this research, the authors analyzed beryl samples of known provenance with laser-induced breakdown spectroscopy (LIBS).

LIBS is a spectroscopic analytical technique that incorporates a laser, a focusing lens, optical fibers, a broadband spectrometer, a CCD camera, and a computer. A tiny portion (sub-microgram) of the sample is melted, vaporized, atomized, and partially ionized into a microplasma. As the microplasma cools, it emits visible light, which is captured and recorded as a LIBS spectrum in the 200–980 nm range. Since damage to the sample is minimal and most elements emit photons in the LIBS spectral range, this technique is suitable for database development.

The structure of beryl, which consists of hexagonal rings (each composed of six Si^{4+}-O^{2-} tetrahedra), allows for substitution of ions with a variety of sizes and charges. Thus, beryl stores reliable chemical information related to its formation environment. The authors examined 39 samples, including aquamarine, goshenite, heliodor, and morganite, which were collected from 13 pegmatite deposits in New Hampshire, Connecticut, and Maine. Twenty LIBS spectra were randomly taken from each sample, focusing on inclusion-free areas. Each spectrum left a crater ~400 μm in diameter. All the spectra clearly showed the major elements Be, Si, Al, and O, along with traces of Ca, Na, Li, and other elements in lower concentrations. Beryl chromophores such as Fe, Ti, Mn, Cr, and V are transition metals with low-intensity peaks; thus, a LIBS spectrum is not sensitive to beryl color. The collected LIBS spectra showed the chemical complexity of their host pegmatites. Beryl from individual zones—core, core margin, and intermediate—of the Palermo No. 1 pegmatite in New Hampshire could be successfully differentiated by LIBS spectra.

However, the current database is insufficient to identify beryls from chemically complex pegmatites. This study is a pilot project for collecting LIBS spectra from tens of thousands of beryls worldwide for the purpose of provenance determination. The authors also suggest collecting

beryl samples from every zone of their host pegmatites to establish a reliable database.   *KSM*

TREATMENTS

Correlations between admixtures and color centers created upon irradiation of natural beryl crystals. E. M. Ibragimova [ibragimova@inp.uz], N. M. Mukhamedshina, and A. Kh. Islamov, *Inorganic Materials*, Vol. 45, No. 2, 2009, pp. 162–167 [in Russian].

Gemstones suitable for jewelry use are rare in nature, but there are vast resources of colorless stones suitable for color enhancement. The objective of this article was to reveal the correlation between impurity concentrations ("admixtures") and color centers induced by neutron and gamma irradiation of beryl.

Beryl irradiated with neutrons acquired attractive colors depending on the type and content of admixtures. However, high levels of induced radioactivity make this type of enhancement impractical. Different colors of beryl without induced radioactivity were obtained by irradiation with gamma rays. An iron content of 0.1–0.2% resulted in a light green color, while stones with 0.5–1.0% Fe turned yellow. Beryl with appreciable cesium and scandium contents acquired pink, orange, and green colors. The formation of the various color centers and their stability depended on the valence state of the iron admixture and on the type of ion charge compensators.   *GL*

"Deutscher Lapis": Der Nunkircher Jaspis und seine Verwendung ["German lapis lazuli": Jasper from Nunkirchen and its use]. H. Schmitt, *Lapis*, Vol. 34, No. 9, 2009, pp. 20–24, 62 [in German].

In the 19th century, the gem industry in Idar-Oberstein was bolstered by the dyeing of agates, mainly from Brazil. During this time, it was discovered that white-to-red-to-purple jasper from Nunkirchen (approximately 65 km west of Idar-Oberstein) was perfectly suited for blue dye. The dyed jasper strongly resembled lapis lazuli and was widely marketed as "German lapis lazuli." The starting material was mined by a local company and a gem cutting firm from Idar-Oberstein. This dyed jasper was fashioned into a wide range of jewelry and other objects such as letter openers, most of which were exported to the United States. The first mine closed shortly before World War II, and a significant drop in demand and high production costs finally led to the closing of the second mine in the 1970s.   *RT*

The effect of HPHT treatment on the spectroscopic features of type IIb synthetic diamonds. I. N. Kupriyanov [spectra@uiggm.nsc.ru], Yu. N. Palyanov, A. A. Kalinin, A. G. Sokol, A. F. Khokhryakov, and V. A. Gusev, *Diamond and Related Materials*, Vol. 17, 2008, pp. 1203–1206.

In this study, annealing of type IIb synthetic diamonds at temperatures up to 2650°C and pressures of 7–7.5 GPa did not change the intensity of boron-related features in the mid-infrared spectrum, nor did it produce any new IR absorption features. For synthetic diamonds with very low boron concentrations (~1 ppm), similar annealing treatment for one hour produced an intense cathodoluminescence band centered at about 2.85 eV (435 nm), which formed as a result of dislocations generated by plastic deformation in the diamond lattice. The study demonstrates that substitutional neutral boron is a very stable defect in diamond, unlike nitrogen, which changes with HPHT annealing. The study results are in agreement with theoretical calculations predicting a very high activation energy for the migration of boron in the diamond lattice.   *JES*

Photoinduced H1b and H1c centers in some natural treated diamonds. E. Gaillou [gailloue@si.edu], E. Fritsch, and F. Notari, *Diamond and Related Materials*, Vol. 17, 2008, pp. 2029–2036.

The effects of UV exposure on the optical absorption of treated-color diamonds were studied with FTIR and UV-Vis absorption spectroscopy. Three brown-to-yellow irradiated and annealed type Ia faceted diamonds (0.11–0.27 ct) were chosen for study. FTIR and UV-Vis spectra were collected for each sample before and after 15 minutes' exposure to UV radiation, and again after exposure to visible light. All three samples showed photoinduced H1b and H1c centers after UV exposure. A decrease in the 595 nm absorption was observed as the H1b and H1c absorptions increased. Recovery of all photoinduced absorptions occurred after the samples were exposed to a standard incandescent 100-watt lamp for several seconds or were stored in the dark for several days.

The authors propose that the observed behavior of the photoinduced centers, all of which are nitrogen related, supports previous studies suggesting a relationship between the 595 nm center and the H1b and H1c centers. While the details of the interaction mechanism are not known, exposure to UV radiation appears to induce H1b center formation by consuming 595 nm centers. The close relationship between these two centers may aid in gem identification, since testing for photoinduced H1b and H1c centers has already proven useful in identifying irradiation and annealing treatment in some stones.   *EVD*

Pink diamond treatment. E. Erel [e.erel@gubelingemlab.ch], *Rapaport Diamond Report*, Vol. 32, No. 2, 2009, pp. 126–127.

A 0.36 ct light brown type Ia diamond was subjected to three processes: HPHT treatment, irradiation, and low-temperature annealing. This produced a homogenous purplish pink face-up color, with a planar color distribution resembling that of a natural-color type Ia pink diamond. The zoning showed delicate colored graining as very narrow to wide purplish and pink bands in a colorless matrix. Treated pink-to-red-to-purple diamonds usually

have a combination of straight, angular, and irregularly shaped color areas. Both long- and short-wave UV radiation reactions of the stone were, however, consistent with those of other color-treated type Ia pink diamonds, showing a combination of orange and chalky green-yellow fluorescence of weak intensity. The color origin was typical of treated pink diamonds: Single-nitrogen/single-vacancy (NV⁻) centers and absorption peaks at 637 nm and bands at 570 nm, as well as weaker H3 and H4 color centers, were created during the multi-step process.   *ERB*

MISCELLANEOUS

Cleaner production practices in a medium sized gold-plated jewelry company in Brazil: When little changes make the difference. B. F. Gilman [biafgian@unip.br], S. H. Bonilla, I. R. Silva, and C. M. V. B. Almeida, *Journal of Cleaner Production*, Vol. 16, 2008, pp. 1106–1117.

The article analyzes the "clean" production steps taken by a manufacturer of gold-plated jewelry in São Paulo, Brazil. The company revamped its entire manufacturing process, including hazardous waste disposal, and realized savings of $115,881 by the second year of the program. The greatest savings were realized through the addition of chemicals that extended the useful life of the electrolyte solution critical to the plating process. Strategic monitoring of electricity use resulted in an 18% savings in utility costs, while more efficient water use brought a 35% savings. This firm is one of 200 jewelry manufacturing operations around São Paulo and 560 throughout Brazil. The authors suggest that the conservation measures practiced by this manufacturer could serve as a model for the others.
                              RS

Deadly combat over natural resources: Gems, petroleum, drugs, and the severity of armed civil conflict. P. Lujala, *Journal of Conflict Resolution*, Vol. 53, No. 1, 2009, pp. 50–71.

This article examines how different types of resources affect the severity of civil wars. It analyzes various civil wars over the past 60 years that have been fought in areas producing oil, gems, and illicit drug crops. The conclusion, drawn mainly from events in Angola and Sierra Leone, is that conflicts over gem resources tend to be more violent—largely because deposits are spread over wide areas that are difficult to control.   *RS*

Diamonds and Human Security: Annual Review 2009. Partnership Africa Canada, 2009, 24 pp., www.pacweb.org/documents/annual-reviews-diamonds/ar_diamonds_2009_eng.pdf.

This year's PAC *Annual Review*, available in English and French, includes detailed reports on more than a dozen diamond-producing countries. The review claims that the Kimberley Process Certification Scheme (KPCS) is failing, and that failure would be disastrous for the diamond industry and the countries and people who depend on it. Accountability is the main issue, with no single entity ultimately responsible for the KPCS's actions or inactions, failures or successes.

Weak monitoring, procrastination, questionable official statistics, and a lack of enforcement by the KPCS and governments have enabled abuses of the system to continue in many countries, thus depriving governments of badly needed tax revenues. The individual country reports include statistics and analysis of the current situation, and some conclude with recommendations for action. Before the establishment of the KPCS in 2003, about 25% of the world's diamond trade was illicit, with diamonds used for money laundering and tax evasion, narcotics and weapons trafficking, sanctions busting, and terrorist financing. The Kimberley Process was created to change this, and it has made a difference. A positive example is Sierra Leone, which legally exported less than $2 million of diamonds in 2000 and now exports between $100 and $150 million annually. Yet official statistics for Lebanon, which has no diamond mining and very little polishing capacity, show exports of 250,000 carats more gem-quality diamonds than are imported. To solve the problems afflicting the KPCS, the report called for reform and enforcement at a November 2009 meeting in Namibia. [*Abstractor's note*: The meeting subsequently failed to reach consensus on these issues, including Zimbabwean compliance.]   *EJ*

Livelihoods and production cycles in the Malagasy artisanal ruby-sapphire trade: A critical examination. L. E. Cartier [laurentcartier1@gmail.com], *Resources Policy*, Vol. 34, 2009, pp. 80–86.

This article examines how ruby and sapphire production factors affect the livelihoods of small-scale miners in Madagascar. Artisanal mining is associated with a vulnerable livelihood mainly due to its primitive methods. It is usually quite migratory, with immigrants "chasing finds" as they seek to escape poverty, but many factors stand in their way. Polluted water, damage to rainforests, and health and safety issues such as HIV/AIDS invariably arise. The environmental effects of artisanal gem mining are grave, especially with illicit and unregulated mining. Racketeering and criminal activity are also critical issues; miners must sell their goods, but in many cases they lack efficient channels to do so. Treatment techniques such as heat and diffusion also play a role in whether the miners can sell their goods; effective treatment allows their low-quality stones to be salable.

Although Madagascar plans to further develop large-scale mining, there are many more people involved in artisanal mining. There is an urgent need to improve the social and environmental conditions of an ever-growing population dependent on gems for their livelihood.
                              MK

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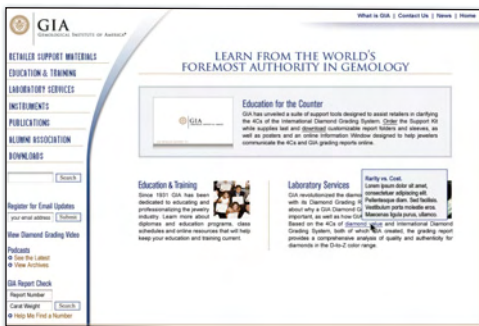Zaitseva O.A., see Zaitsev A.N.
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