

VOLUME XLVII

GEMS & GEMOLOGY

SUMMER 2011

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*Advancing the Science
and Business of Gems*

PROCEEDINGS OF THE FIFTH INTERNATIONAL GEMOLOGICAL SYMPOSIUM

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Travel grant funds for a limited number of presenters who demonstrated appropriate need were provided by Wayne and Dona Leicht, Alice Keller, and GIA.



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May 29–30, 2011 | Carlsbad, California

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PDF versions of individual articles and sections from Spring 1981 forward can be purchased at gia.metapress.com for \$12 each. Visit gia.edu/gandg for free online access to the 1934–2009 subject and author index and all 1934–1980 issues.

Gems & Gemology's five-year impact factor (for 2005–2009) is 1.737, according to the 2010 Thomson Reuters Journal Citation Reports (issued June 2011). *Gems & Gemology* is abstracted in Thomson Reuters products (*Current Contents: Physical, Chemical & Earth Sciences* and Science Citation Index—Expanded, including the Web of Knowledge) and other databases. For a complete list of sources abstracting *G&G*, go to gia.edu/gandg.

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Gems & Gemology is published quarterly by the Gemological Institute of America, a nonprofit educational organization for the gem and jewelry industry.

Postmaster: Return undeliverable copies of *Gems & Gemology* to GIA, The Robert Mouawad Campus, 5345 Armada Drive, Carlsbad, CA 92008.

Our Canadian goods and service registration number is 126142892RT.

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ABOUT THE COVER



The 5th International Gemological Symposium, "Advancing the Science of Business and Gems," continued the tradition of past GIA symposia by focusing on key gemological and economic issues facing the gem and jewelry trade. On display at GIA during the event were several of Wallace Chan's creations, including the "Rose Maiden" titanium brooch, shown here, which features a 16.74 ct mandarin garnet set with rubies, red spinels, and diamonds. Courtesy of Wallace Chan, Hong Kong; photo by Robert Weldon.

Color separations for *Gems & Gemology* are by Pacific Plus, Carlsbad, California. Printing is by Allen Press, Lawrence, Kansas.

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GIA SYMPOSIUM 2011: ADVANCING THE SCIENCE AND BUSINESS OF GEMS

On May 29–30, more than 730 people from 35 countries gathered in Carlsbad to attend GIA's 5th International Gemological Symposium. Like the four previous symposia, this conference provided a mixture of thought-provoking presentations on both the science of gemology and the challenges facing the business of gems. Unlike the others, this one was held at home, on GIA's main campus overlooking the Pacific Ocean, with GIA's talented staff as hosts and hostesses.

"The new normal is abnormal," declared Steve Forbes, chairman of Forbes Media, as he opened the event. To meet the needs of a global economy, he said, the world needs a global currency—one backed by a modern gold standard. And to thrive in the current economic environment, a business leader must know how much risk to take, relentlessly strive for innovation, and be able to deal with crisis.

In the research sessions, Caltech's Dr. George Rossman and dozens of other prominent speakers explained the gemological applications of instrumentation such as LA-ICP-MS, explored the challenges of identifying treated and synthetic diamonds and colored stones, and examined new techniques in pearl characterization.

Best evidence that it was an effective Symposium: I can't stop thinking about what the speakers said!

—Peggy Jo Donahue, MJSA

During the business sessions, Gallup's Ken Royal reported that today's consumers gravitate more toward well-being and experience than material objects. Designer Wallace Chan mesmerized the audience with his philosophy of jewelry design, in which he combines a wide range of disciplines and summons all his energies to express three dimensions and light. Luxury marketing strategist Scott Galloway announced that "the Web is dying"—and being replaced by new, dynamic forms of social media such as Facebook. With the new generation of luxury consumers, being perceived as digital and innovative is a must.

Rick Harrison of the reality television series "Pawn Stars" recounted how he made his Las Vegas pawn shop an attractive alternative for resale by embracing in-depth historical knowledge. Sustainability expert Dr. Brian Nattrass demonstrated how responsible practices can be good for the environment and good for business.

Supporting both tracks were the 63 poster presentations on topics as diverse as the separation of natural from synthetic emeralds, hallmarking, coral conservation, and the identification of treated pink synthetic diamonds. It truly was a "marketplace of new ideas," as coined by Symposium founder Dr. Vince Manson at the first gathering in 1982.

Symposium concluded with the debate center, "Shipwrecked!"—where leaders from industry and academia exchanged their views on the benefits of ethical business practices and the challenges of economic sanctions, identifying conflict diamonds, and implementing fair trade practices. As Martin Rapaport noted, "The bottom line is

**Inspired! Wonderful!
Enlightening! Fascinating!
I left Symposium refreshed and awed.**

—Douglas Mays, Wild & Petsch

that *you* are responsible for what you buy. You have the economic power. . . . There has to be an economic incentive for evil people to stop being evil, not just negative punishment."

Many special gems and pieces of gem-set jewelry were on display during the event, including the Steinmetz Sunrise, a cushion-cut 100.67 ct Fancy Intense yellow diamond; more than 30 innovative designs by Wallace Chan; a 111.96 ct unheated Burmese star sapphire courtesy of Symposium poster presenter Benjamin Zucker; and the award-winning Vega Tahitian cultured pearl jewelry set by speaker Robert Wan.

Summaries of all the presentations are included in this Proceedings issue of *G&G*, as are photos of speakers, museum displays, and social events. Consult the index to locate a specific speaker or poster presenter.

None of this could have been accomplished without the countless hours invested by our presenters, the Symposium planning committee and team leaders, and dozens of GIA volunteers. We are particularly grateful to Dr. Jim Shigley and Brendan Laurs, who organized the research sessions; to Dona Dirlam, who organized the poster session; and to events manager Carol Moffatt and Symposium coordinator Kathy Gilmore. We were especially honored to join GIA president Donna Baker and Board chair Susan Jacques as hosts of this, the 5th International Gemological Symposium.

*Kathryn Kimmel and
Alice Keller, Co-Chairs*



Editor's note: This issue also includes an article on one of the timeliest topics in the gem community: the red gem feldspar known as andesine, reportedly mined in Tibet.



NAVIGATING THE CURRENT ECONOMY FOR BUSINESS GROWTH AND SUCCESS

The three-year recession may have ended, but much of the world still struggles to recover. It was against this backdrop that Steve Forbes, chairman of Forbes Media, opened the 5th International Gemological Symposium with his keynote address.

“The new normal is abnormal,” said Forbes, likening the current unemployment and economic stagnation to the turmoil of the 1930s and 1970s. “This is the first time we’ve had such a slow recovery.”

“Why aren’t we doing better? What are the headwinds keeping us back?”

Forbes presented three barriers to economic recovery, starting with the monetary policy of the U.S. Federal Reserve. For nearly a decade, he said, the central bank has been printing too much money, without any oversight. This policy has caused turbulence among currencies worldwide, preventing a sustained recovery.

“The price of everything went up, encouraging speculation and distorting the price of things. What is the real price of a barrel of oil? How much of that is hedge fund speculation?”

Forbes asked the audience to imagine the uncertainty that would result if the federal government handled the way it does money and changed the length of an hour every day. He said that same type of instability applies to the dollar. This fuels diplomatic disputes and makes planning and inventory management profoundly difficult.

A global economy with increasingly sophisticated supply chains, he continued, demands a global currency. In the 19th century that currency was the British pound, but today it is an unstable and greatly diminished U.S. dollar. Here Forbes offered his first prediction, one he admitted might sound “very strange” today: Within five years, the dollar will be linked to the price of gold. Rather than the traditional gold standard, it would be a more modern version. He pointed to the precious metal’s intrinsic value and the spectacular growth of the U.S. economy during the 19th century, when the dollar was pegged directly to gold. “Gold is the North Star,” he said.

The second headwind Forbes addressed was government



Steve Forbes opened the 5th International Gemological Symposium with a keynote address on the economic recovery and the fundamental qualities of business leadership. Photo by Eric Welch.

spending: “One of the modern myths is that governments create money. . . . Money does not come from heaven or Mars, it comes from people in the marketplace.”



According to Forbes, the U.S. Federal Reserve has been printing too much currency, causing instability and hindering America's economic recovery. Photo © iStockphoto.

Voters have begun to realize, Forbes contended, that heavy government spending on health care and public pensions is unsustainable. Citing major budget cuts in the United Kingdom and the state of New Jersey, he predicted similar measures would soon be enacted in Washington, DC.

Forbes said government spending should only be used to finance specific needs—health care not among them. He described health care as a huge opportunity for entrepreneurs, drawing an analogy with an even more basic necessity: food. Farmers grow food and technology creates new ways of delivering it, all in a free market, with food banks and other safety nets in place for the needy. Forbes maintained the same could be done for the health care market.

The third headwind Forbes addressed was America's complicated tax code. While the U.S. Constitution is 7,200 words long and the Bible runs about 700,000 words, he pointed out, the U.S. income tax code contains some 10 million words. Forbes said that nobody—not even tax experts or the Internal Revenue Service—knows exactly how to interpret all of it. Meanwhile, Americans spend 7.5 billion hours each year filing their taxes. “This code,” he

said, “has spun out of control.”

Forbes predicted that the existing U.S. tax code would be thrown out and replaced by a simplified flat tax with generous exemptions. Such an overhaul, he said, would encourage business expansion and “unleash people's energies to focus on real things.”

After his keynote address, Forbes was joined by GIA president and CEO Donna Baker for a question-and-answer session and fielded questions from the audience.

Not surprisingly, his prediction of a gold standard prompted several questions from a gathering of gem and jewelry professionals: How would it affect the jewelry industry? Would it make it easier to manage inventories? Would it force an end to gold speculation?

Forbes said a gold standard would have a positive impact and provide stable value, though he declined to predict where the price of gold would be fixed. He cautioned against getting caught up in speculation. “Keep gold as an insurance, but not as an investment—unless you know what you're doing.”

Regarding the consumer trend toward ethically sourced, socially conscious jewelry and gemstones, Forbes said the attention should be focused on a country's underlying political and social conditions rather than boycotting its exports, an “indirect approach (that) doesn't make much of an impression.”

Forbes, a former presidential candidate who has written extensively on leadership, was also asked to describe the qualities that are critical for today's business leader. He named three: the art of knowing how much risk to take, a sense of innovation, and the ability to deal with crisis.

To illustrate these fundamental qualities, he related the story

After the keynote address, GIA's Donna Baker joined Forbes onstage for a stimulating question-and-answer session. Photo by Eric Welch.





Kim Piracci poses a question to Forbes. Photo by Eric Welch.

of Amadeo Giannini, an Italian immigrant who started a small bank in San Francisco in 1904. The Bank of Italy began as a lender to the city's immigrant population, which other banks refused to serve. Giannini applied that same spirit of innovation and calculated risk-taking to help businesses flourish, including the nascent California wine and motion picture industries. Within three decades, his small business had become Bank of America.

Giannini also embodied the third essential leadership trait, crisis response. When a catastrophic earthquake struck San Francisco in 1906, he had the presence of mind to remove the assets from his bank vaults before the ensuing fires consumed them. Hauled by wagon to a safe rural location, these funds later helped rebuild the city. Giannini also had the vision to handle crises such as the Great Depression and World War II.

Asked about the future of print media, the publishing mogul stressed that magazines will remain relevant. While online media continue to capture an increasing share of the market, he noted



Amadeo Giannini, an Italian immigrant whose small business eventually became Bank of America, embodied Forbes's three qualities of leadership: the art of taking risk, a sense of innovation, and the ability to deal with crisis. Photo © Corbis.

that readers still enjoy the tactile nature of magazines. He predicted that print and online media would continue to coexist, just as radio has survived several transformations. And as with any other industry, innovation will be pivotal.

"Doing something that others aren't is the key," Forbes said. "Add value, don't be a commodity."

Stuart D. Overlin



5TH INTERNATIONAL GEMOLOGICAL SYMPOSIUM: A PHOTOMONTAGE



Left: Symposium co-chairs Dr. James Shigley, Kathryn Kimmel, Alice Keller, and Brendan Laurs with keynote speaker Steve Forbes (middle). Far left: On display during Symposium was an emerald cross and rosary from the Nuestra Señora de Atocha shipwreck, courtesy of Ellen Weatherbee. Below: GIA president Donna Baker welcomes attendees; Patrick Peys describes the work of the Antwerp Diamond Squad.



Above, left: "Shipwrecked" debate panelists Dr. Brian Natrass, Richard Drucker, Dr. George Rossman, Martin Rapaport (speaking), and Tom Cushman, with moderator Susan Jacques. Above, right: Drs. Natrass and Rossman listen to Drucker's remarks. Left: Cotha Vinod poses a question during the debate session.

OPENING SESSION AND DEBATE CENTER

Right: Wallace Chan, with Agatha Kessler, discusses his design philosophy. Below: the “Unfettered” brooch by Wallace Chan, with 21.84 carats of pink and blue sapphires and 0.71 carats of diamonds. Middle: Rick Harrison of the television series “Pawn Stars”; GIA student Krishna Choudhary.



BUSINESS TRACK



Above: Stuart Robertson opens the “Future of Gemstones” panel. Left: Celia Mamby chats with Peggy Harding before one of the Business sessions.



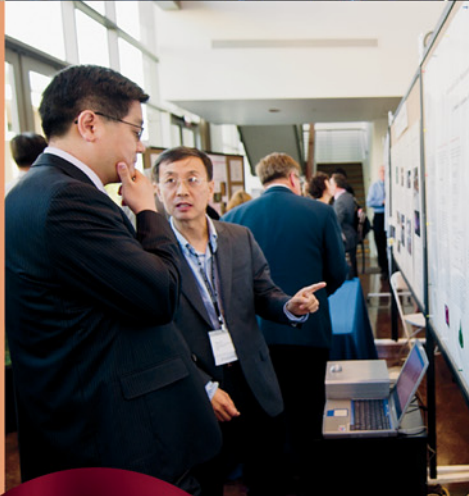
Clockwise from top left: Dr. Mark Newton; Kenneth Scarratt; Dr. Ahmadjan Abduriyim; the "Sunrise," a 100.67 ct Fancy Intense yellow diamond, courtesy of the Steinmetz Group; Dr. Emmanuel Fritsch; Dr. Chakka-phan Sutthirat; Richard Taylor.



RESEARCH TRACK



Below: Poster session chair Dona Dirlam with K. C. Bell and David Humphrey. Right: Danusia Niklewicz explains jewelry hall-marking. Middle: Dr. Yan Liu discusses his poster with Dr. Wuyi Wang; Symposium attendees explore some of the 63 poster presentations on display.



POSTER SESSION



Left: A 111.96 ct unheated Burmese star sapphire, courtesy of Treasured Gems and Jewels LLC/Benjamin Zucker. Above: Russell Shor and Barbara Mooty.



SOCIAL EVENTS



Clockwise from top left: the "Vega" necklace and earrings, featuring Tahitian black cultured pearls (courtesy of Robert Wan); music from the Fabulous Pelicans; Nirupa Bhatt chats with Symposium guests; dinner on GIA's Ocean Terrace; Drs. George Harlow, Frank Hawthorne, and Bram Janse at the GIA Alumni welcome reception; Dr. Lutz Nasdala converses at breakfast; attendees from Shree Ramkrishna Export in Mumbai stand at the entrance to the GIA Library; Alexander Wai Kai Leung and Tasana Pattaratar.

Right: Pala Chief mine owner Bob Dawson (blue shirt) shows the former location of large gem pocket. Below: An 88.4 g emerald crystal from Coscuez, Colombia; courtesy of Gene Meieran.



FIELD TRIPS



Above: Stewart mine owner Blue Sheppard (far left) takes guests underground; Mark Mauthner explains the geology of the Oceanview mine. Far left: John Chapman ponders a photo of a crystal cave at the "All That Glitters" exhibit. Near left: Rob Ayotte studies a sample from the Stewart mine; Abhay Mehta admires the Balboa Park Carousel egg.



WHERE IS LUXURY IN THIS BRAVE NEW WORLD?

Keynote Speaker

Ken Royal Senior Client Services Manager,
Gallup

Panelists

Amit Dhamani CEO and Managing Director,
Dhamani Jewels

Nicolas Luchsinger Vice President of Retail Operations
for the Americas, Van Cleef & Arpels

Ulrik Thaysen Vice President of International
Retail, Pandora

Moderator

Susan Jacques President and CEO, Borsheim's
Fine Jewelry and Gifts

This panel brought together four unique perspectives on high-end retail. A consultant from the world's leading public opinion organization offered critical insight into the attitudes and spending behavior of today's luxury consumer. Joining him were senior executives from three successful international jewelry brands, who presented their own strategies for engaging with affluent clientele.

KEN ROYAL

The session's keynote address began with a look at Gallup's recent consumer surveys. A poll of randomly selected U.S. households

Keynote speaker Ken Royal revealed Gallup's latest insights into U.S. and global public opinion, as well as the importance of connecting with consumers' emotions and need for trust. Photo by Valerie Power.



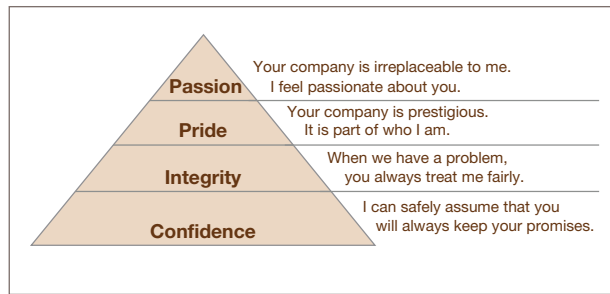
Ulrik Thaysen, Nicolas Luchsinger, Susan Jacques, Amit Dhamani, and Ken Royal participated in the panel. Photo by Valerie Power.

showed that consumer spending is considerably lower than it was three years ago, even among higher-income individuals. Most of the respondents added that this change in spending represents the "new normal" for them, though the sentiment could reverse with an improvement in the job market.

The polls also showed an uptick in President Barack Obama's approval rating after the death of Osama Bin Laden. When people are more positive about the president, Royal pointed out, they tend to be more positive about the economy. He added that economic confidence index numbers have generally been rising in the United States, though it is too early to tell if that trend will be sustained.

Next, Royal presented Gallup's world polls, which measured sentiment on law and order, governance, jobs, economics, migration, food and shelter, infrastructure, and health care in more than 150 countries. The poll's migration index showed that 700 million adults—16% of the global population—would like to move abroad permanently. Most expressed a desire to relocate to the United States, Canada, Spain, Saudi Arabia, Australia, and other "places where success is likely to happen," according to Royal. Countries likely to see the largest surge in population density in the years ahead include Singapore, Saudi Arabia, New Zealand, Canada, and Australia.

According to Gallup's well-being metric, which evaluates overall quality of life, 25% of the world's population reported



This Gallup illustration connects the luxury buying experience to the hierarchy of emotional attachment. According to Ken Royal, most jewelry retailers stop at the purchase experience and never reach the higher levels of emotional engagement.

itself as thriving, while 62% are struggling and 13% are suffering. Denmark enjoyed the highest thriving percentage, 72%, compared to just 1% of Togo's population. In the United States, 53% were thriving and 3% said they were suffering. The highest well-being index of any U.S. city belonged to Boulder, Colorado. Southern California also scored high, while the metric was dramatically lower in the country's so-called Rust Belt, where industrial jobs have been dwindling for several decades.

While the old adage says, "You can't buy happiness," Gallup has shown this is not entirely true. In wealthier countries, the population tends to have a higher well-being index. But high income does not always *guarantee* well-being, Royal added. In recent years, Egypt's gross domestic product has increased while its well-being index has fallen sharply, creating a pattern where the population's high expectations are not being met. A similar recipe for unrest has taken place in Tunisia. While there remains a vast gulf in the distribution of wealth in China and India, he noted that more of their citizens are saving money and becoming hopeful about the future.

Royal, the former chief operating officer of a family-owned jewelry store chain, then turned to the jewelry industry. Today's luxury consumer often gravitates toward well-being and experience rather than material objects. As a result, jewelry must now compete against travel, physical fitness/appearance, and technology. Retailers can adjust to this landscape by connecting their product to the emotional benefits of giving. Rather than competing with life moments such as weddings, anniversaries, and birthdays, they can align with them. Royal showed brain scans revealing clear differences in neural activity between high passion and low passion, noting that 70% of purchases are based on emotion rather than reason.

Another crucial aspect is trust. Asked which professions they trusted the most, Americans ranked firefighters first, with "high" or "very high" marks from 90% of those surveyed. Nurses, members of the armed forces, and the clergy also measured quite well. Jewelers scored only 20%, compared to 15% for members of

Congress and 7% apiece for car salespeople and lobbyists. Asked to name the most important consideration when shopping for fine jewelry, 40% said it was the quality of the item. Yet the level of trust in the store was nearly as important, at 32%. Interestingly, loyalty measured slightly higher for online retailers than for brick-and-mortar jewelers.

Royal closed his address with some considerations on selling the store experience:

- Is your store intimidating or inviting?
- Is it about a purchase or a relationship?
- Is it a place where your customers want to be?
- Do your salespeople spend 70% of their time on customers' rational needs or on their emotional desires?
- Do you transform the purchase experience into an experience that enhances well-being?

NICOLAS LUCHSINGER

Van Cleef & Arpels opened its first boutique in 1906, next to the Ritz Hotel on Place Vendôme in Paris. As Luchsinger noted, the brand was successful from the very beginning and became a favorite among royalty and entertainers. The family's heirs continued to operate the firm until 1999, when it was sold to fashion conglomerate Richemont. Today, Van Cleef & Arpels is strategically positioned in markets such as Russia, Dubai, and the Middle East. Sales in Asia have been exceptionally strong, particularly in colored diamonds.

Luchsinger pointed to VCA's tradition of responding to crisis with innovation. During the Great Depression it invented the Mystery Setting, an invisible mounting that has appeared in many of its finest creations. Later that decade, its designers created the zipper necklace, inspired by the Duchess of Windsor. During World War II, the firm moved its flagship store to New York's Fifth Avenue. Its signature clover motif was unveiled amid the economic turmoil of the 1970s.

A new crisis emerged on September 15, 2008, the day Lehman Brothers filed for Chapter 11 bankruptcy protection. In the global recession that soon followed, even high-net-worth individuals curbed their spending. To stimulate sales, the company began inviting a select group of clients to Paris for weeklong shopping experiences. These featured private tours of jewelry workshops, helicopter rides to castles, meetings with VIPs, and personalized jewelry presentations. Through these experiences, Van Cleef & Arpels has successfully engaged with its most exclusive clientele.

AMIT DHAMANI

With the rapid emergence of the Chinese, Indian, and Russian markets, the global luxury consumer has a new face. And it is the

newly wealthy who are pushing luxury markets to unprecedented heights. Citing the astronomical prices paid at international jewelry auctions since 2008, a development that has generated some skepticism, Dhamani was confident that the spending spree would continue: “This individual is always looking for something unique.”

Dhamani presented a brief overview of the company his father started as a gem wholesale business in 1965. Entrusted with repositioning it as a luxury retailer a decade ago, the younger Dhamani hired a top brand strategist to capitalize on the firm’s heritage and reputation. In Dubai, the company enjoys one of the world’s premier upscale markets. Along with its excellent infrastructure and relentless passion for luxury, the city is a leading destination for tourists. According to Dhamani, these tourists have different demographic preferences. Arabs generally purchase for weddings, and Indians for festivals such as Diwali. Chinese shoppers usually have something very specific in mind and do not want a sales pitch, while Russian shoppers tend to be more impulsive. The company places great emphasis on understanding these differences and creating jewelry designs and products that align with particular nationalities. Each year the company hosts 75 seminars and workshops for targeted clients, which include business councils, the diplomatic corps, and cruise passengers. These events feature jewelry models who are trained to discuss the pieces they wear. The company does not purchase radio or television advertising, preferring the more exclusive approach of sponsoring events at polo clubs and golf resorts.

Acknowledging the prevailing uncertainty in the Middle East and northern Africa, Dhamani said it presented an opportunity for “exponential growth” in Dubai if tourism shifts from there from the areas in turmoil. He was even more optimistic about the future of the high-end market, concluding that “jewelry is a luxury and will be a luxury forever.”

ULRIK THAYSEN

Since its launch in Denmark in 1982, Pandora has captured a significant portion of the affordable luxury segment, with a global network of 10,000 points of sale in more than 55 countries. The firm’s cornerstone product is a charm bracelet that allows more than 800 different silver, gold, glass, and gem components to be mixed and matched. Pandora is a lean, vertically integrated company with skilled in-house designers in Copenhagen, its own production factories in Bangkok, a wholesale distribution network, and branded concept stores.

Thaysen outlined Pandora’s mission: “to offer women across the world a universe of high-quality, hand-finished jewelry.” The core attributes of the brand are genuine materials that have a fem-



Pandora’s cornerstone product is its charm bracelet. This 14K gold bracelet contains gold, brilliant-cut diamond, and cultured pearl charms. Courtesy of Pandora.

inine, romantic touch and inspire the wearer to create and combine collections that express her individuality.

He noted that Pandora is coming off a remarkable 2010, in which it sold 57.5 million pieces of jewelry. The company also introduced a line of watches, more than doubled the number of its branded concept stores from 196 to 421, and formalized a collaboration with GIA to train its store staff. As the company continues to grow and add new products, he added, it will stay true to the Pandora image and concept.

Thaysen then presented a brief video that distilled Pandora’s best practices into the following areas:

1. Controlling its brand presence through branded sales channels
2. Developing a retail assortment that focuses on the winning products, and keeping them consistently in stock
3. Tailoring its approach to entering new markets, either alone or in close partnership when necessary
4. Focusing on its core products—bracelets and charms—that are “the Pandora DNA”
5. Executing established sales tools and platforms through its retail managers’ guide

In closing, Thaysen said Pandora is still a young company “acting unconventional in a conventional world.”

Stuart D. Overlin

JEWELRY DESIGN: FROM THE MASSES TO MUSEUMS

Speakers

Wallace Chan	Jewelry Artist
Martin Katz	Jewelry Designer
Shivan Sarna	Show Host, HSN
Moderator	
Huw Daniel	President, Platinum Guild International USA

Popular jewelry designs now appear in a variety of venues, from museums to the red carpet to television shopping channels. A designer's success is measured by the ability to capture the attention of jewelry lovers and move them to wear a piece of art.

How designers achieve this success was the topic of this panel discussion. Moderator Huw Daniel kicked off the session with an overview of popular jewelry designs, suggesting that trends are launched when celebrities start to wear certain styles and retail customers strive to emulate them. He also offered an overview of the latest trends:

- Increased use of colored gems, including vibrant, dramatic, shocking colors
- A mix of precious and semiprecious metals
- The use of negative space, stemming from the high cost of precious metals
- Vintage-inspired jewelry
- Stacking and layering
- The impact of runway trends (designs, textures)
- "Less is more"
- The dominance of white metals in the bridal market and a resurgence of platinum in the United States in 2010

WALLACE CHAN

Wallace Chan, a renowned designer from Hong Kong whose museum-quality pieces were exhibited for the first time in the U.S. at GIA's Carlsbad campus, shared his fascination with gemstones and his intentions as he creates jewelry art.

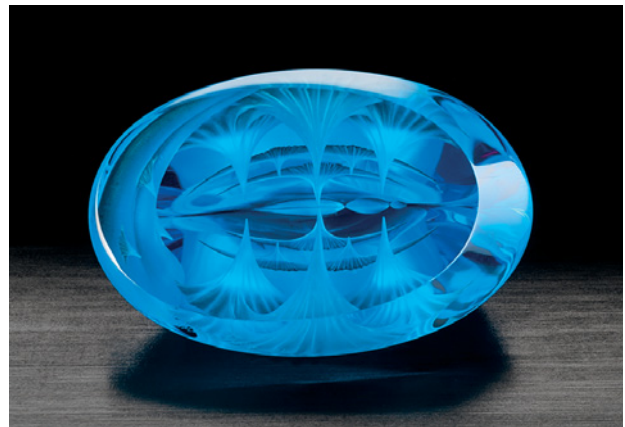


Panelists Wallace Chan (with translator Agatha Kessler, far left), Martin Katz, and Shivan Sarna field questions from the audience. Photo by Valerie Power.

"Precious stones bear the vast mysteries of the universe," he said. "The strength permeating [them] is tightly interlocked with humankind: It shapes our thoughts, demonstrates power and wealth, expresses our love, stimulates our minds, and charms us all."

Chan began his artistic career weaving sweaters at age 13 and became an ivory carving apprentice by the time he was 16. "I was a poor boy who had to work day and night to put food on the table," he said.

"Exotic," Wallace Chan's 772 ct blue topaz sculpture, was on display at GIA during the Symposium. Photo by Robert Weldon.



Exposed to Western carving in a graveyard, he began a quest to express three dimensions and light in his works. Today he is known for his innovative Wallace Cut, which combines the art of intaglio and cameo carving with gemstone faceting to create multiple reflections in a single work, what he calls the “dialogue of the gemstone with light.”

“I sculpt from my heart and from my hands, integrating the material into the emotional realm,” he said. “To delineate the spiritual through forms has all along nourished my world of sculpting and carving.”

Chan said that each gemstone has a life force that draws him to it.

“They fascinate me with their brilliant colors, guide me with their textural lines, inspire me with their various shapes and sizes, and touch me with the language of their soul,” he said. “And even more so, it is as if they want to attract me with their unique inclusions, gazing at me, enticing me to spy on their innermost beauty, constantly evolving and continuously processing in the mind until it is filled with the intrinsic sound of resplendent colors.”

Chan added that a true designer must be proficient in multiple disciplines, including physics, chemistry, chromatics, ergonomics, metallurgy, gemology, and psychology. “It is also important to have the unique aesthetic sense and standard of a designer, the passion and breadth of mind of an artist, and the way of thinking of a philosopher.”

“In the process of jewelry design and making, we are fortunate to be able to fully apply the proven knowledge of other disciplines, and under the guidance of the merciful wisdom of our predecessors, we can then discover and present the ultimate essence of the gem, its most picturesque and poetic glory,” he said.

He shared his experience of creating the Wallace Cut as an example of pushing himself to the breaking point to create new art.

In the “repeated, incessant calculations of light reflection and stone carving, and the repeated attempts at amalgamating all the relevant techniques together—I pushed myself to the corner. But only in those continuously extreme moments of concentration could one focus on each minute detail. . . . And in the sculpting process, the attempts to communicate with light and reflections, I almost drove myself to the pinnacles of madness,” he said.

That was when he summoned all his energies to evoke the magic of light and shadow, beyond the material realm.

“When the mind concentrated on each of these legends and stories of the gem, gazing at their spiritual forms and physical structures, it was as if the moment was frozen, the gem and I became one,” Chan said. “The soul was touched, and then and there it was the viewer’s ‘gemstone moment.’”

MARTIN KATZ

Martin Katz, a longtime favorite of the Hollywood elite, began adorning celebrities with his jewelry in 1992, when Sharon Stone

asked to wear his pieces to the premiere of *Basic Instinct*.

“I wasn’t in the business of loaning jewelry at the time,” he said, explaining that it was not a normal practice. But when the head of Paramount Pictures asked him to do it as a favor, Katz obliged, asking to receive credit for the pieces in any magazine coverage of the premiere. Soon he was regularly walking the red carpet with celebrities who introduced him as their personal jeweler. He has jeweled more than 500 Hollywood stars since.

“It’s the repetitiveness that sticks with the audience,” he said. “One red carpet won’t change your life, but the repetitiveness, combined with advertising and editorial, makes success.”

In the beginning the limelight was a thrill, Katz said, and the notoriety brought attention to his designs. Still, he did not want the “jeweler to the stars” label. He wanted to be known for the quality of his work, not the people he associated with.

“But it opened so many doors for me. *Extra* and *Entertainment Tonight* came to my store before every red carpet to show what the celebrities would wear, and I was on *Oprah* two times,” he said. “The impact of the celebrity endorsement brought me to the awareness of others, like Victoria’s Secret and Ray-Ban.” Katz designed a \$5 million bra for Victoria’s Secret in 2008.

He found that statement pieces—large, theatrical jewelry—showed up best on the red carpet, as did vintage jewelry. After asking himself if he wanted to do theatrics or do business, he began to create “contemporary jewelry with an old soul.”

These teardrop earrings demonstrate a pairing of contemporary and classic styles. They feature pear-shaped tanzanites, 43.20 carats total weight, with diamond shields and diamond beads micro-set with blue sapphires. Courtesy of Martin Katz.



Katz said the trend for the luxury/celebrity market is toward classical and traditional pieces, with an emphasis on textures, manipulating metals, and placement of diamonds.

He said many of his clients have plenty of money, despite the recession, but the new way of thinking is “to not look like you’re indulging too much when everyone else is suffering.”

He has also seen more people investing in gemstones as assets. “De Beers has to parcel out [their rough] because the demand in China is so strong. The asset-collecting mentality is taking over the world. Dealer after dealer is bumping up the price.”

Still, Katz advised audience members to not get caught up in the frenzy.

“Buy the best. Buy what you know. Quality, I believe, will always be king.”

SHIVAN SARNA

Shivan Sarna, a Graduate Gemologist and HSN show host for nearly 12 years, said she enjoys educating the shopping network’s millions of viewers about the jewelry they purchase, especially by touching on the science and romance behind the stones.

“No one needs jewelry, but we want it,” she said. Sarna explained how she uses that “psychology of acquisition” and emotional storytelling to move her customers to “buy now.” HSN can shift in real time (“the storefront changes every day”) to respond to consumer demand. Each year, the network ships nearly 6.15 million jewelry products.

Sarna urged the audience to connect with their customers by learning the technique of smiling while they talk. “I know it feels

weird and it’s not easy, but it makes a tremendous difference,” she said. “It’s not a big deal connected to gemology, but it is a huge

HSN CUSTOMER DEMOGRAPHICS

- Large, loyal customer base
 - 4.6 million customers
 - 44% 12-month repeat rate
 - Best customers increased 7% in Q4 2010
- 82% female
- 25–65+ years old (including 46% in the highly valued 35–54 age bracket)
- 87% homeowners
- \$65,000+ household income
- \$521 annual spend (up 5.5% from previous year)
- Top markets: New York, Los Angeles, Philadelphia, Chicago

connection to sales.” She also emphasized making eye contact and giving the customer space.

When they’re ready, educate them about what they are looking at. “Start with the romance, finish with the science,” she said. “You’re selling the dream: the ability for people to wear art.”

Amanda Luke

DIGITAL AGE MARKETING: ARE YOU STILL PARTYING LIKE IT'S 1999?

Keynote Speaker

Scott Galloway Clinical Associate Professor,
NYU Stern School of Business

Moderator

Thomas Yang Senior Vice President of International,
Callaway Golf Company

The Web is dying." These were surprising words, especially from the head of a digital marketing think tank. But Symposium keynote speaker Scott Galloway was referring to the traditional Web as we have known it for the past 15 years. More and more, Internet users are switching to social media and mobile applications. Rather than visiting a brand's website, they are going to its Facebook presence or turning to Twitter. And these changes are reshaping the way companies connect with consumers.

Galloway noted that the recession forced us to reevaluate traditional notions and opened our minds to innovation. One result was the emergence of social media, led by Facebook and Twitter.

Demographic trends are driving the social media phenomenon. Over the last 15 years, 150 million new luxury consumers have come online worldwide. Some 600 million more will follow in the next 15 years, many of them from outside the United States and the other G-10 nations. These high-net-worth individuals will have a social network profile. "And new money loves prestige," Galloway continued, adding that talk of Generation Y being less materialistic is "rubbish." With Generation Y expected to eclipse the baby boomers in spending by 2017, he said, we are entering a "golden age of prestige."

The new luxury consumer is remarkably different, however. "They aren't reading the newspaper," said Galloway. "They aren't reading magazines the same way we did. . . . They have a different

relationship with technology." With the new generation of luxury consumers, being perceived as digital and innovative is a must.

Meanwhile, dramatic changes are taking place in the Internet landscape. Since 2007, MSN's and Yahoo's shares of global time spent online have fallen sharply. While Google still enjoys high usage, little time is actually spent on each search—and its share is still only half of YouTube's. Facebook, though, has captured a 12% share. By next year the site is projected to have a billion users worldwide—a number that could reach 1.5 billion if China allows full access. As Facebook continues to create interesting features that add value, it could breach the 50% mark worldwide within three years. Never, said Galloway, has a technology been adopted so rapidly.

With Facebook and the other top 10 websites receiving three-quarters of all Internet traffic, everyone else is fighting over an increasingly small share. He predicted that within a few years, "the Internet will simply be the platform that powers Facebook."

But, as Galloway showed, ad spending has not kept pace with these trends. While 26% of U.S. media consumption time in 2009 was spent on the Internet—even more for the sought-after young, affluent consumer—only 12% of all advertising dollars were spent there. Mobile phones represented another 14% of media consumption time but only received 1% of the advertising spend.

Many retailers, particularly older males from the baby boomer generation, have resisted social media because of its "unseemly" lack of privacy or out of an impulse to cling to the past. To stay relevant in luxury, Galloway said, retailers must overcome this resistance and take advantage of the new marketing opportunity. He urged attendees to consider how much time and resources they are dedicating to Facebook and Twitter, because "something very special" is happening right now: the transition from a rental



Scott Galloway, director of digital marketing research firm L2, spoke on the social media phenomenon and its opportunities for luxury retailers. Photo by Valerie Power.



Mobile phone applications and social media tools such as Facebook and Twitter are changing the face of marketing. Photo © iStockphoto.

model of advertising to an ownership model.

Traditional advertising only “rents” the attention of the consumer. This is a costly model, as evidenced by the \$700 million L’Oréal spent on magazine advertising in 2010. Through the transformative technologies of social media and mobile phone apps, marketing is headed toward ownership: a direct relationship with consumers. Galloway cited Ivanka Trump’s Twitter presence as an example of the ownership model. Two-thirds of her Tweets are snapshots of her life, but the other third are pure marketing for Trump Hotels. In effect, she has the equivalent of the entire population of Miami following her, listening directly to her content and sharing it with others—instantly.

According to Galloway, this kind of digital outreach in attracting and serving luxury consumers will separate the winners from the losers in the new media landscape.

Last year Galloway’s think tank, L2, published its second annual “Digital IQ Index: Luxury.” The study measured the digital outreach of 72 global luxury brands, based on dimensions of (1) website and e-commerce; (2) search, email, and online advertising; (3) social media presence; and (4) mobile apps. The brands fell into five categories:

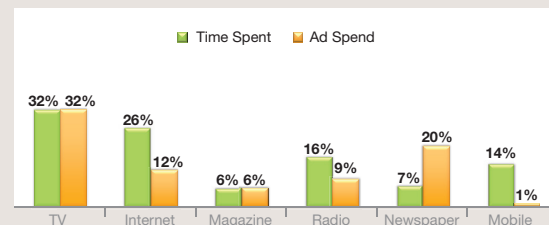
- Genius: digital as a competitive differentiation
- Gifted: brand-enhancing, experimenting digitally, conversion-oriented
- Average: functional but predictable, with few innovation leaps
- Challenged: poorly integrated purchase/product experience or limited engagement beyond the Web
- Feeble: nascent digital footprint, not committing appropriate resources

The Fashion brands—led by Coach, Louis Vuitton, and Ralph Lauren—scored exceptionally well. The lowest-performing category, however, was Watches & Jewelry. Aside from a handful that ranked as “Gifted,” they were either “Challenged” or “Feeble,” despite their considerable brand equity.

Galloway closed his remarks and answered audience questions with additional advice for luxury retailers:

- Think of social media as the population of a vast, untapped country. China is not the biggest opportunity—Facebook is.
- Be innovative—or at least be a fast follower, like Apple. Digital outreach is inexpensive, so never be afraid to take risks and occasionally fail. His mantra: “Ready, fire, aim.”
- Facilitate evangelists through content such as live chat, user reviews, and Facebook “likes.” User reviews are the fastest way to stimulate sales on a site, so never be afraid of some negative reviews. This immediacy invigorates the brand.
- Take advantage of email marketing, “an unbelievably untapped resource.”
- Have a data mindset and read websites such as Mashable.com to stay informed on social media trends. If necessary, hire a company to manage your Facebook presence.

U.S. MEDIA CONSUMPTION VS. AD SPEND (2009)



While the Internet and mobile phones have gained large amounts of media consumption time, advertising spending has not kept pace with this development.

Galloway encouraged the audience to bring life to their brands by taking their content—all the history, heritage, and romance of the product—and putting it into social media.

Stuart D. Overlin

THE FUTURE OF GEMSTONES AND GEMSTONES OF THE FUTURE

Keynote Speaker

Stuart Robertson Research Director,
Gemworld International

Panelists

Martin Rapaport Chairman, The Rapaport Group

Stephen Lux President and CEO, Gemesis
Diamond Company

Douglas Hucker CEO, American Gem Trade
Association

Robert Wan CEO and Founder, Tahiti Perles
and Robert Wan Tahiti

Moderator

Peggy Jo Donahue Director of Public Affairs, MJSA



Douglas Hucker answers a question from the audience while fellow panelists Robert Wan, Stephen Lux, Martin Rapaport, and Stuart Robertson look on. Photo by Eric Welch.

This panel examined supply and demand and pricing trends for the products that form the basis of the jewelry industry: diamonds (including synthetics), colored stones, and cultured pearls. The speakers assessed current conditions and offered an outlook on the future of the gemstone market.

STUART ROBERTSON

In his keynote address, industry observer Stuart Robertson noted that the last few years have altered the gem landscape.

“The future promises great opportunities,” he said, but not necessarily for traditional markets such as the United States and Canada, where conditions remain “stable at best.” The prospects appear much better for emerging, transitioning markets.

In colored stones, there is now more competition at the source. While this trend has led to higher prices, it has also encouraged exploration and stimulated an appetite for less-traditional stones. The diamond industry, meanwhile, struggles to find financing and credit. Many banks and lenders are hesitant to reinvest in the diamond industry, Robertson said, because of an overreliance on memo, a model that “has been abused to the point that it’s not a sustainable business practice.”

In the pearl industry, the central theme has been the massive influx of attractive Chinese freshwater cultured pearls. Robertson did not consider these production levels sustainable, however. Of all gems, cultured pearls are the most susceptible to environmental forces, and he predicted that Chinese producers would eventually face natural challenges similar to those that plagued the

Japanese industry two decades ago. Robertson pointed out that the traditional trade model is giving way to a new model characterized by:

1. Producers selling directly to the consumer, competing with retailers for profits.
2. Sovereignty over mineral rights and the nationalization of mines.
3. An emphasis on responsible practices: “There needs to be action behind them, not just buzzwords.”

The changing model has created an opportunity for a new generation of products: natural minerals not typically associated with jewelry; treated gems, including coated and HPHT-processed material; and blended composites such as low-quality rubies filled with lead glass. However, the abundance of low-grade starting material that can be processed into salable products has redefined the word *gem* and distorted the concept of rarity. And the industry continues to struggle with proper disclosure. “We’ve created an environment where there’s incentive to be less than forthcoming,” Robertson said. Acknowledging there is no perfect solution, he added that “protecting consumer confidence should be the aim of each market tier.”

Robertson described this as a period of opportunity and growth, as advances in technology and communication energize production and sales. While exceptional and unique gems comprise the top tier of the market, the vast majority of products fall outside that category. The industry, then, should pair with fashion rather than investment as it adapts to a much different consumer market.

MARTIN RAPAPORT

Taking on the issue of synthetic diamonds, Martin Rapaport defended them as “a stepping stone to the real thing. They create desire.” This democratization “has turned on millions who never thought they’d buy diamonds.”

Rather than looking at synthetics as a threat, he said, the diamond industry should embrace a symbiotic relationship with them. His advice was to focus on the “Three D’s”: Detection, Disclosure, and Documentation.

“Tell the truth,” he urged the audience. “I’m not afraid of synthetics, as long as we can tell the difference between what’s authentic and what’s not.”

Rapaport said the jewelry industry must always meet the demand for romantic tokens of love and affection. Whether that means a natural or synthetic or imitation diamond, what matters is the idea behind the product. “Retail profit margins shouldn’t be limited to what comes out of the ground,” he said.

“Diamonds are more than what they are,” Rapaport continued. “We are selling the *idea* of diamonds. People want what they can’t have. They treasure what they have that other people can’t have.”

While there is no guarantee that American jewelers will retain their position in the industry, Rapaport insisted that the global demand for natural diamond would continue to rise, especially as more Chinese and Indian consumers “experience the joy of jewelry.”

STEPHEN LUX

Gemesis director Stephen Lux offered the manufacturer’s perspective on synthetic diamonds, noting the “incredible interest and strong opinions” generated by the products. In recent years his company has commercialized the two known technologies for diamond growth: CVD (chemical vapor deposition) and HPHT (high pressure, high temperature).

Lux reported that Gemesis is now achieving larger sizes. Its near-colorless products routinely exceed one carat, many of them with a G or H color grade.

“Their origin is fully known and properly disclosed on every report,” he said, adding that “deception must be avoided at all costs.”

He called GIA’s decision to issue grading reports for lab-grown diamonds “the right thing to do for the consumer.” Unfortunately, he added, the public still does not grasp the difference between the terms *synthetic* and *simulant*. Lux, who referred to his company’s product as either *lab-grown* or *lab-created*, said the term *synthetic* poses a problem, as it “suggests a fake.”

He predicted that Gemesis would achieve million-carat annual production capacity within a decade. Asked when the market would see 5–10 ct synthetic diamonds, he said they are probably still a generation away, although the company has produced some



These jewelry pieces showcase colorless and yellow lab-grown diamonds created by Gemesis. Courtesy of Gemesis.

yellow larger than 4 ct. He added, “It’s a safe bet that colorless won’t stop at one carat.”

While the Gemesis brand will be available through select retailers, Lux said the company plans to sell most of its goods directly to the consumer through online retail. That way, he added, “the producer can disclose and manage the story.”

DOUGLAS HUCKER

The female self-purchaser is no longer buying colored gemstones, said Douglas Hucker: “She’s buying *color*.” And when it comes to color, jewelers have no shortage of tools. One is Pantone, which provides color products and services for designers of all types. There are also fashion councils that decide, months in advance, on the trendy colors for clothes, cars, and other merchandise. Hucker added that by reading fashion magazines and websites such as *fashiontrendsetter.com*, jewelers can merchandise the right colors.

Another tool he recommended was AGTA’s Gemstone Information Manual, which spells out the various gem enhancement methods and assigns standard codes to them. CIBJO and ICA have adopted these codes, and while the terminology is still not unanimous, “you at least have to be making an effort to disclose properly.” More than ever, the consumer demands information, and it must be communicated clearly.

Gem products also face more stringent regulation from federal governments. The Tom Lantos Block Burmese JADE Act, for instance, prohibits Burmese rubies from being imported into the United States. Hucker encouraged the audience to consult the Jewelers Vigilance Committee website (jvclegal.org) and learn about the various guidelines concerning money laundering, treatment disclosure, and irradiated gemstones.

Hucker urged the jewelry industry to pay attention to corporate social responsibility. “You need to consider the impact of what you’re doing, and what effect it will have throughout the chain Being a good citizen is important to your survival because the consumer will demand it.”

ROBERT WAN

Tahitian cultured pearl pioneer Robert Wan presented an overview of the pearl industry. He noted the Japanese akoya’s sharp decline over the last two decades, the result of financial turmoil, pollution, climate change, and fierce competition from new players, particularly China. While South Sea and Tahitian cultured pearls have suffered from overproduction in recent years, Wan said that production limits and transparency reforms should restore price stability and profitability.

He said the market is now “flooded” with Chinese freshwater cultured pearls. Production of these goods jumped from 20 tons in 1981 to 1,500 tons in 2008. Meanwhile, several new producing countries have emerged in the Pacific, including New Zealand (abalone shell), the Marshall Islands (black cultured pearls), and Vietnam (freshwater and akoya cultured pearls).

Pearl culturing involves living organisms, which makes it an inherently risky proposition. Overproduction can cause asphyxiation or disease, while hurricanes and typhoons can destroy a pearl farm overnight. But the greatest threat, Wan said, is climate change: A temperature fluctuation of just 2° or 3°C can be fatal to a mollusk.

Wan observed that cultured pearls represent only 2–5% of jewelry sales overall. There is clearly room for the market to expand, and he emphasized creativity as a selling point. “The

design of pearl jewelry, the new ideas and concepts, the exploration of baroque and other stunning shapes, the amazing colors . . . all of this gives so much room for creation.” He pointed to the Tahitian Pearl Trophy and other international design contests as a way to bring fresh ideas from all over the world.

According to Wan, Hong Kong has become the world center for the pearl business. Hong Kong holds more wholesale auctions than any other city, and its three annual jewelry fairs are the pearl industry’s largest. Dubai, meanwhile, is making a concerted effort to become an international trading center. Another one to watch is the new “China Pearl and Jewelry City” of Zuhji, near Shanghai, which will have some 5,000 offices, shops,



Knowing color trends is one of the keys to jewelry merchandising. Pantone color management tools are just some of the many resources available to jewelers. Photo © iStockphoto.com.

and studios employing an estimated 100,000 trade professionals.

As the cultured pearl industry continues to mature and restructure, Wan said, it must conquer new markets with an aggressive commercial strategy that includes specialized exhibitions and auctions. He named China, India, Dubai, Brazil, and Turkey as the most promising new markets.

Stuart D. Overlin

EVERYTHING OLD IS NEW AGAIN: THE APPEAL OF THE AUCTION, ESTATE, AND VINTAGE MARKETS

Speakers

Gary Schuler Senior Vice President and Director,
New York Jewelry Department,
Sotheby's

Stephen Silver Chairman and CEO,
S. H. Silver Company

Rick Harrison Star of History's series *Pawn Stars*,
The Gold & Silver Pawn Shop

Moderator

John Green President and CEO,
Lux Bond & Green

It was a familiar refrain during several business track sessions of the 2011 GIA Symposium: Tell the story. People love to hear the history. That's what sells.

It especially resonated during the auction, estate, and vintage jewelry panel, as the speakers discussed the growing popularity of pre-owned and historically significant jewelry.

GARY SCHULER

The proof is in the sales, according to Schuler, who pointed out that the combined jewelry sales for Sotheby's and Christie's reached an all-time high of \$827 million last year.

The excitement began in 1987 with the auction of the Duchess of Windsor's jewels, which documented one of the most fabled romances in history. The intriguing provenance pushed prices to seven times their fair market value, resulting in a \$50 million sale.

"Crowds waited around the block outside of our offices in New York," Schuler said. "That sale is what brought notoriety to jewelry auctions and established the format for 'lifestyle' auctions."

Jewelry sales for the two auction houses continued to climb from there, to \$350 million in 1990, \$500 million in 1995, and \$690 million in 2007. Among these were some extraordinary individual diamonds: the 35.56 ct Wittelsbach Blue sold for \$24.3 million in 2008, and in 2010 the 24.78 ct Graff Pink brought \$46.2 million.

Schuler noted the growing interest in selling items at auction, which offers the global brand recognition of the auction house,



Panelists Gary Schuler, Stephen Silver, and Rick Harrison share a light moment. Photo by Eric Welch.

transparency of transactions, and the ability to reach every likely buyer around the world with comprehensive marketing and promotion. He added that there are equally strong incentives to buy at auction: easy access to information and opportunities to bid, the expertise of jewelry specialists, and a broad range of goods, styles, makers, and price points, with a focus on rarity.

The auction houses have seen a shift from trade buyers in traditional markets to private buyers in emerging markets. Asian customers increased from 6% of total buyers in 1995 to 20% in 2010, and Asian purchases represented approximately 30% of annual jewelry sales the last two years.

"People have a comfort level buying from an auction," Schuler said, and that gives them the opportunity to acquire a good value. "Some items may be much more expensive on Fifth Avenue."

In a strong market, Schuler said, more than 60% of the lots sold exceed the high estimates.

He ended his remarks by sharing specific examples of how Sotheby's has used effective storytelling to surpass expected prices.

- **Promoting the stories behind the jewels:** An 8.66 ct Burmese ruby and diamond ring, from the collection of famed philanthropist and patron of the arts Isabella Stewart Gardner, was estimated at \$1–1.5 million, and sold for \$2.1 million (\$242,000 per carat).

SOTHEBY'S JEWELRY AUCTION OVERVIEW

- The 2010 sales drew participants from 83 countries.
- The average annual spend by a jewelry auction buyer in 2010 was \$275,000, compared to \$80,000 in 1995.
- The average price of a jewel sold by Sotheby's in 2010 was \$93,000.
- There has been a shift from trade buyers in traditional markets to private buyers in emerging markets.
- Asians represented 20% of total buyers in 2010, with Asian purchases accounting for approximately 30% of annual jewelry sales in the last two years.
- In 2010, Sotheby's sold a magnificent pink diamond (24.78 ct Fancy Intense pink, VVS₂) for \$46.2 million to London jeweler Lawrence Graff. This price, against an estimate of \$27–\$38 million, placed it in the realm of fine art masterpieces.

- **Providing the context for rarity:** A ring containing a 10.46 ct Internally Flawless Fancy Light pink diamond reportedly from India's fabled Golconda region, estimated at \$1.4–\$1.6 million, went for just under \$2.3 million (\$217,000 per carat).
- **Creating a buzz:** A 30.48 ct D-Flawless oval diamond was promoted as "The Perfect Gift." Estimated at \$3.3–\$3.8 million, it fetched \$4.1 million (\$135,000 per carat).
- **Emphasizing jewelry as decorative art and showcasing superb craftsmanship and design:** A plique-à-jour enamel pendant brooch by Marcus & Co., ca. 1900, was estimated at \$40,000–\$60,000 but brought \$302,500.

"It's all about romancing the stone," Schuler said. "It's always about the story: People love the story."

STEPHEN H. SILVER

Silver agreed, saying that while estate and antique jewelry represent only 2% of the marketplace, "We still have great stories to tell."

He explained how developments in science and technology have influenced the artistic capabilities of designers over time. The advances in how gemstones could be cut, for instance—from the saw to torch to laser—can be seen in jewelry's progression from the Art Nouveau and Edwardian styles to Art Deco.

"That had a tremendous impact, both positive and negative, on how we cut," Silver said.

He went on to tell the stories behind some of the pieces he

has acquired over the years, including the Cranberry diamond; the Irving Scott Corsage Ornament, which he donated to the GIA Historical Collection in 2003; and the Cullinan Blue Diamond Necklace, which he donated in 2010 to the Smithsonian National Museum of Natural History, where it is on permanent exhibit.

Silver purchased the Cranberry as a 1.66 ct Fancy Vivid purplish pink and had it recut to a 1.46 ct Fancy purplish red. "I overpaid for it by 20% at the time, but the intensity and saturation of the material was so beautiful" that he saw the potential for dramatic improvement. "It was truly the most amazing transformation," he said, calling it one of the most aesthetically pleasing red diamonds he has seen.

Silver discovered the Irving Scott Corsage Ornament in Saratoga, California, when the last remaining heir of the ship-building magnate asked him to see 250 pieces that were tucked away in a garage safe. Silver said that by examining the hallmarks and stamps of some of the pieces, he could trace the family's movements back to 1780. The corsage ornament is of French Belle Époque provenance and features an unheated 40+ ct Russian pink topaz.

RICK HARRISON

Harrison is a storyteller of a different ilk, whose tale of success veers sharply from the usual career path in the gem and jewelry industry.

This 24.78 ct Fancy Intense pink emerald-cut diamond with VVS₂ clarity sold for \$46.16 million, a record price for any jewel sold at auction. Courtesy of Sotheby's.





The Cullinan Blue Diamond Necklace, which dates back to 1905 and contains 5.32 carats of blue diamonds, is one of the pieces Stephen Silver has acquired over the years. He donated it to the Smithsonian National Museum of Natural History in 2010. Photo by Harold & Erica Van Pelt; courtesy of S. H. Silver Co.

A self-described “born hustler,” he dropped out of high school to pursue a \$2,000-a-week fake Gucci bag business. Then he waited years for the population of Las Vegas to pass the 250,000 mark, when city officials would issue an additional pawn shop license. He paid \$20,000 for a license that is

worth close to \$2 million today, he said.

Now the star of History Channel’s reality television show *Pawn Stars* and owner of The Gold & Silver Pawn Shop, Harrison said most of the shops in Las Vegas are owned by large corporations. They simply type an item’s description into a computer to get a price.

He decided to “change things up” and began to emphasize the origins, lore, and history of the items in his shop, because “that’s what people get excited about.” He began to consume history books and all the information he could find.

“I am the biggest nerd you will ever meet in your life,” Harrison said. “I read three to four hours a night.” As far as his shop’s merchandise, they’re “not the most glamorous items, but there are a million little things you can tell people, and I give my staff 10-minute history lessons on every object that comes in.”

Harrison also calls on a pool of experts to determine the authenticity of items and fill in any missing information gaps. He said customers appreciate this honesty and the transfer of knowledge that takes place.

“The day you think you know everything is the day you go out of business,” he said.

Harrison’s business model has helped propel *Pawn Stars* to the highest-rated cable television show in the United States. The show’s success helps draw 4,000 people to the store each day, bringing in 6,000 to 7,000 items per month. And it’s made him a reality TV star. “If I walk into the store, business ceases,” he said.

In the session wrap-up, Silver said he feels shows such as *Pawn Stars* and *Antiques Roadshow* have been good for the auction and estate jewelry industry. “They are credible shows by credible people and have set the barometer for what we do, so people are more open to a discussion of reality. They have been a positive development.”

Amanda Luke

PLAYING A BIGGER GAME: BETTER BUSINESS FOR A BETTER WORLD

Keynote Speaker

Dr. Brian Nattrass Founder, Sustainability Partners

Moderator

Bev Hori Vice President of Education and
Chief Learning Officer, GIA

The gem and jewelry industry has a huge advantage over other products in terms of sustainability, according to Dr. Brian Nattrass, founder of one of the world's leading consultancies on sustainable enterprise.

Why? Because jewelry has been worn for 100,000 years as a way to express the intangible messages of prestige, love, and power.

"It's so interesting, as a social scientist, how intrinsic to being human jewelry is," he said. "It's really a long sustainability story for your industry. What I find so fascinating is that when talking about sustainability, there is no other commercial enterprise that has got sustainability in its roots as jewelry and gems do."

And the fact that metals and gems come from the earth itself means "we're really talking the same language: Sustainability and the gem and jewelry industry go hand-in-glove," he said.

Dr. Nattrass spoke of the Brundtland Commission, created by the United Nations in 1983 to study the effect of population growth, technology, and consumer demand on Earth's resources. The final report, published in 1987, defined sustainable development as the ability to meet the needs of the present generation without compromising the ability of future generations to meet their needs.

Since then, business has replaced government as "the most powerful institution on the planet," and it needs to take responsibility for making sure the planet's resources can support the population.

"This is a new role for business, not yet understood and accepted," Dr. Nattrass said. "It's about investing ourselves in a task of historic proportions. Sustainability and the whole emerging climate change really is the issue of the moment."

The U.S. Army, one of Sustainability Partners' clients, is taking the topic of climate change and its implications for security "extremely seriously," he said.

"The military sees the world being squeezed. We're using up the good things on this planet that are required for human life," Dr. Nattrass said. "Our life-supporting resources are declining, while our consumption of life-supporting resources is growing."

He described the "shadow side" of global megatrends as an exploding population, a widening income disparity, rising



Dr. Brian Nattrass, characterizing our present course as "inherently unstable and unsustainable," offered examples of corporations that are making sustainability an integral part of their operations. Photo by Eric Welch.

resource consumption, pollution, and ecological stress. The evidence is seen in a variety of developments:

- The Arctic icecap has shrunk 22% since 1979. Continued thawing of the polar icecaps will cause the seas to rise three to four feet (more than a meter) by the end of the century.
- Water scarcity: Only 1% of the world's freshwater is suitable for direct human consumption.
- Twenty percent of the world's population owns 86% of the assets.
- The world population has tripled in our lifetime and will reach 9 billion between 2030 and 2050.
- Oil production has been flat for four years, and there is a growing gap between oil supply and demand.

The U.S. Army considers energy, water, and the environment the critical factors for global stability in this century. When these factors are not in balance, Dr. Nattrass said, people live in poverty, suffer high mortality, and move closer to armed conflict. "It is a breeding ground for disaffection, dissatisfaction, and unhappy people. There are real changes in natural systems that are most likely to happen in regions of the world that are already fertile grounds for terrorism," he said, which creates a new security paradigm.



The audience prepares for Dr. Natrass's presentation. Photo by Eric Welch.

"Terrorism is a much smaller threat than climate change."

Dr. Natrass emphasized that the path we are on is "inherently unstable and unsustainable." We need to reconsider everything: how we source, manufacture, sell, transport, and handle our products' end of life; how we grow our food; and how we ensure our security.

"We are one integrated system. What happens in China does matter to us," he said. "What are we going to do about it? Are we prepared to invest ourselves in a task of historic proportions?"

Dr. Natrass shared examples of companies that have committed to sustainability and outlined some the benefits they have reaped:

- Lower expenses for resources, transportation, and waste
- Enhanced innovation of products
- Increased market share as more and more consumers look for sustainable products
- Better public perception
- Greater competitiveness and profits

"You don't have to compromise who you are, no matter what your brand is," he stressed. "You don't have to sacrifice anything—quality or image—just bring yourself to this new enterprise and do it your way."

CASE STUDIES

Starbucks created a program called Shared Planet to educate its customers about why they should care about sustainable products. Their slogan: "It's Bigger Than Coffee."

"Starbucks really gets it because everything they sell is food, which is really vulnerable," Dr. Natrass said. "When the climate changes so it is untenable to grow coffee, tea, or sugar, then they are out of business."

The company identified three main sustainability areas:

- Certified ethical sourcing of 100% of its coffee by 2015
- Environmental stewardship: creating "green" stores that save energy and water and are LEED certified (an international standard for green buildings), while making food and beverage packaging completely recyclable
- Contributing millions of hours to community service

"The idea is that when the customer buys a product from them, they are making the world a better place," he said.

Wal-Mart, the world's largest non-oil corporation, set out to be 100% supplied by renewable energy and to create zero waste. The company sends its own sustainability assessment to each of the 100,000 suppliers it works with to make sure they meet such criteria.

"Wal-Mart is having an amazing impact all the way down the supply chain," Dr. Natrass said.

This has produced savings in energy and distribution costs, which get passed along to the consumer, and improved efficiency and reduced waste. Sustainability has been good for business.

"It takes all of us working together—collaborating with our suppliers, nongovernment agencies, and the government—on common solutions," said Matt Kistler, Wal-Mart's senior vice president of sustainability, in a video clip.

Nike was the "world's most despised company" back in the late '90s, Dr. Natrass said, when the words "slave labor" and "sweatshops" became associated with its overseas manufacturing facilities.

"They thought that as long as the local laws were obeyed, that was sufficient," he said. But American and European consumers let them know they expected more from a leading brand.

"This really hurt them," Dr. Natrass said. But it also caused Nike to reassess its business model and undergo profound change.

One of the company's first initiatives was the "reincarnation of the sole," which recycles used sneakers to make surfaces for playgrounds. The Nike Environmental Apparel Design Tool, released in 2010, helps designers make responsible choices that address the full life cycle of their products.

"We can engage designers at the earliest stage of the process so we can see the impact downstream," said Lorrie Vogel, general manager of Nike Considered, a program that takes into account every environmental aspect of its products. Nike has collaborated with Patagonia, Wal-Mart, Target, and more than 60 other companies to create apparel standards.

"We believe that it is important to move the industry towards more sustainable innovation," Vogel said.

Amanda Lake

DIAMOND IDENTIFICATION

A CASE STUDY OF NATURALLY IRRADIATED DIAMONDS FROM ZIMBABWE

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The identification of artificially irradiated diamonds remains a challenge for gem laboratories. To better distinguish the treated material, it is important to study naturally irradiated diamonds from different geographic origins. In December 2008, the Kimberley Process published its first profile of rough diamonds from the Marange diamond fields in Zimbabwe (www.diamonds.net/cms/Zimbabwe/docs/Recognize_Rough.pdf). The occurrence of greenish colors suggests that some of the diamonds were naturally irradiated.

The Research Department at HRD Antwerp examined a set of seven rough diamonds from Marange. The samples were analyzed using standard gemological methods and more advanced imaging and spectroscopic techniques, such as examination with the D-Scope gemological microscope and DiamondView imaging, as well as IR, UV-Vis, and photoluminescence spectroscopy. Three of these rough samples were polished and re-examined using the same characterization methods.

All the samples showed typical irradiation features, such as an absorption band at 741 nm, which were easily detected with UV-Vis absorption spectroscopy. Some also showed features due to subsequent annealing. Microscopic investigation revealed green and orange radiation stains, a common occurrence in natural diamonds that have been irradiated or irradiated and heat-treated.

RADIO-COLORATION OF DIAMOND

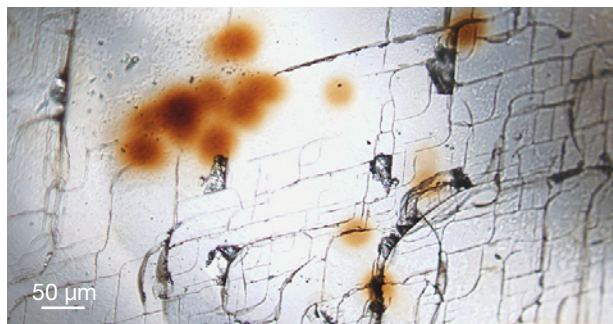
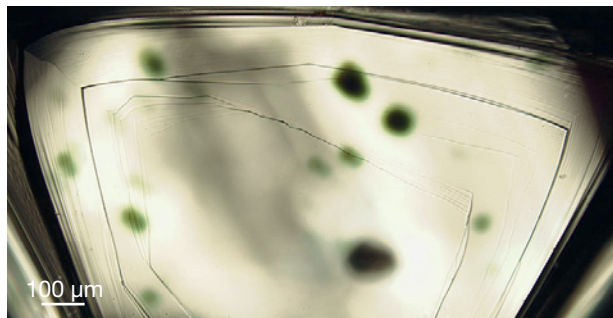
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This study investigated the green and orangy brown spots that commonly occur on the surface of rough diamonds and which are caused by external irradiation by helium ions in the form of alpha particles. These ions are believed to be generated by the decay of radionuclides in radioactive minerals that were located close to a diamond in its geologic past. Helium ions generated in



These radiation-induced surface spots occurred on a diamond crystal from Quebrada Grande, Venezuela (top), and an alluvial diamond from Namaqualand, South Africa (bottom). Photomicrographs by L. Nasdala.

the U- and Th-decay chains have energies in the 4.0–8.8 MeV range; their travel distances in diamond are up to 29 μm . Depending on the sizes (mostly unknown) of the radiation sources and their proximity to the diamond's surface, helium irradiation typically results in blurred round spots with green color. These spots are usually deformed semi-spheres with fuzzy boundaries. With moderate-temperature heating, the green radio-coloration turns orange-brown.

Raman measurements revealed that these richly colored green and brown spots represent elevated levels of radiation damage. The same observation was made on spots produced by the irradiation of diamond plates with 8.8 MeV He ions in a tandem accelerator, followed by annealing experiments. The transformation from green to brown was accompanied by relatively low degrees of structural reconstitution.

Our experiments showed that irradiation with about 1×10^{16} He ions per cm^2 is needed to produce strong radio-coloration. This in turn leads us to conclude that radio-coloration on the surface of natural stones must be a long-term process: A typical spot has a size on the order of $1,000 \mu\text{m}^2$, requiring about 1×10^{11} helium ions. If the helium irradiation emanated, for instance, from a $5 \mu\text{m}$ uraninite crystal (>80 wt.% U), it would take more than 10 million years to accumulate 1×10^{11} helium ions in the neighboring diamond. In the case of a $10 \mu\text{m}$ zircon crystal containing 1,000 ppm of uranium, that same alpha dose would require more than 2 billion years,

Editor's note: Underlined author signifies presenter; asterisk indicates keynote speaker.



Significant color changes are produced by HPHT treatment of natural type IIa diamond. The brown diamond is 0.82 ct and the HPHT-treated colorless stone is 0.84 ct. Courtesy of the DTC Research Centre.

which seems implausible. Therefore, radio-coloration is likely due to the action of small grains of strongly radioactive phases that lay adjacent to the diamond for at least several million years.

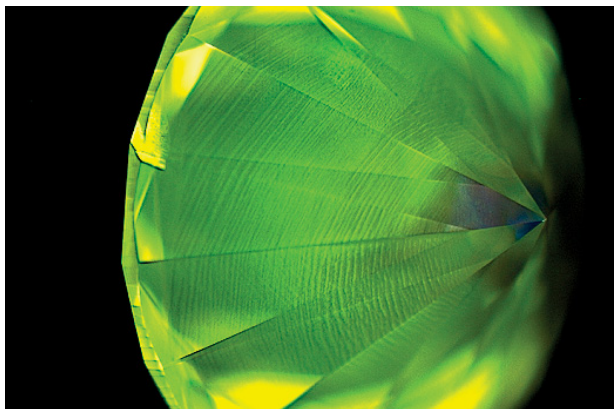
TREATED DIAMOND IDENTIFICATION

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Extrinsic properties of materials are determined by the presence of impurities and defects, and these can be more important than the intrinsic properties. The entire semiconductor industry, for example, is dependent on the ability to add impurities that control a material's electrical properties and remove defects that would degrade the carefully engineered functions. For gem materials that are intrinsically colorless, such as diamond, the presence of impurities and defects can dramatically alter the color and value of the stone.

Many natural diamonds have an undesirable brown hue. Recent research has shown that the brown color is caused by the presence of vacancy clusters, which in natural diamond are created as a result of plastic deformation. For synthetic diamonds grown by the high-pressure, high-temperature (HPHT) process,

Treatments cannot remove some features that reveal that a diamond is laboratory grown. In this 0.56 ct CVD synthetic diamond, the differential uptake of impurity-related defects during growth results in striations that are observable with the DiamondView, even after HPHT treatment. Courtesy of the DTC Research Centre.



the color of the as-grown material is usually determined by the presence of substitutional nitrogen and boron impurities. A range of colors can be produced, including nitrogen-doped yellow-brown, low-nitrogen near-colorless, and boron-doped blue material. Unless rigorous steps are taken to remove nitrogen from the chemical vapor deposition (CVD) growth process, the synthetic diamonds produced will appear brown. There is a strong correlation between the saturation of the brown color and the nitrogen concentration in the process gases. It has been proposed that the brown hue again originates from vacancy clusters, but that the vacancy clusters in the CVD material are different from those in natural diamond. Near-colorless CVD synthetics can be produced by carefully tailoring the growth conditions and excluding unwanted impurities such as nitrogen. Furthermore, adding boron-containing species to the CVD source gas can produce blue CVD synthetic diamonds.

It has been widely reported that the color of both natural and synthetic diamonds can be altered by different treatments. Annealing and irradiation, or combinations thereof, are by far the most common treatments in use today. For more than a decade we have known that HPHT treatment can effectively reduce the coloration of some type IIa brown diamonds, or produce green diamonds from suitable type I brown natural diamond. We have also known that irradiation and annealing can be used to introduce defects that alter the color of a diamond. The types and concentrations of those defects depend on the impurities present in the starting material, the radiation dose, and the annealing conditions. In recent years, there have been numerous reports of diamonds that have undergone multiple treatments to engineer their color.

Although the technological advances in treatments pose some challenges to the identification of genuine natural diamonds, the vast majority of treated diamonds can be rapidly identified by a combination of gemological features, spectroscopic techniques, and the ever-improving knowledge of defect physics in diamond. Annealing under conditions not encountered by natural diamonds and the introduction of large nonequilibrium concentrations of vacancies and interstitials by irradiation damage provide characteristic combinations of color centers that not only indicate treatment but also allow the investigator to infer the nature of the treatment(s). Furthermore, it should be remembered that some telltale features of synthesis or treatment are very difficult, if not impossible, to remove. For example, HPHT treatment of brown nitrogen-doped CVD synthetic diamond can dramatically reduce the absorption in the visible region of the spectrum and change the luminescence characteristics. However, the differential uptake of impurity-related defects during growth on the risers and terraces of surface steps produces striations that are readily observed in DiamondView images of both as-grown and HPHT-treated material, exposing it as CVD synthetic diamond. As the physicist Sir Frederick Charles Frank noted, "Crystals are like people: It is the defects in them that make them interesting."

A REVIEW OF DIAMOND COLOR TREATMENT AND ITS IDENTIFICATION

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The color of diamond is attributed to optical centers, which have selective absorption in the visible light region of the electromagnetic spectrum. Various treatment techniques have been developed to improve the color appearance of natural diamonds by either removing unwanted centers or introducing optimal ones.

Irradiation with or without subsequent annealing has been applied to diamond since the 1950s. Depending on the defect configuration in the starting material, optical centers (including the H2, GRI, NV, 595 nm, H3, and H4) can be introduced, creating a wide range of colors, such as green, blue, yellow, orange, pink, and red. This treatment technique adds color to a diamond, but it cannot remove preexisting colors.

Annealing at high pressure and high temperature (HPHT), a process introduced in the 1990s, is a more dramatic color enhancement. This technique not only removes preexisting colors, but can also produce fancy colors. The major effects of this treatment include the removal of brown color related to vacancy clusters, the release of optically inactive boron, and the formation of other optical centers such as isolated nitrogen, H2, and H3. In addition to decolorizing type IIa and IaB diamonds, HPHT treatment can enhance the blue color in type IIb diamonds and the pink color in type IIa diamonds, or create green, yellow, and orange coloration.

Although irradiation and HPHT treatment have been used separately in the past, recently they have been combined to create colors that cannot be achieved with any single process. While



This 0.24 ct diamond was treated by multiple processes, including HPHT annealing and irradiation, to achieve its attractive Fancy Intense yellowish green color. Photo by C. D. Mengason.

most diamonds in the market that have been subjected to multiple treatments are pink to red, many other colors can also be introduced.

Identification of diamond color treatment has been a challenge in gem laboratories for decades. It has been accomplished mainly by finding the differences in optical defect configurations between known natural-color and treated-color diamonds. These include differences in defect type as well as their concentration, combination, and distribution. Advanced testing methods are required to detect the subtle differences in defect configurations.

GEM LOCALITIES AND FORMATION

THE FUNDAMENTALS IN MINING FOR COLORED GEMSTONES AND MINERAL SPECIMENS

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Mining for colored gemstones and mineral specimens presents unique challenges. Each of the four phases—prospecting, exploration, development, and exploitation—is different from almost every other type of mining. In fact, prospecting is the only phase that shares some characteristics with other commodities. In gem mining, the exploration, development, and exploitation phases usually take place simultaneously: One explores the deposit while developing the structure to find something to exploit. Blasting

could be considered part of the crushing process in most metal mining operations and in sand and gravel quarries. But in gem and mineral specimen mining, one must carefully take the rock apart using a minimal amount of the proper explosive, drill the right pattern for the rock type and the desired outcome, and then detonate the holes in the correct sequence to achieve the proper breakage with minimal damage.

Each gem deposit has its own idiosyncrasies that must be addressed individually; chemical composition and texture can change constantly as mining proceeds, so the owner/operator must be able to read the signs to follow the enriched zone. This usually requires that one person (or a small crew) assume the roles of geologist, driller, blaster, and mucker (i.e., the person who removes the blasted rock). That person will decide on the drilling

direction based on the visual geology, know what they are drilling through by observing the drill cuttings, load the holes far from any enrichment with the proper type and amount of explosives, and detonate them so the main wave front moves away from the enriched area. While mucking, this individual can see if the projection was correct and find any gems that may have been blasted out. Another reason for consolidating the various roles into one person (usually the owner/operator) is that one stone could represent a substantial portion of the entire value of a single pocket. If that stone is stolen, accidentally destroyed, or goes unobserved, significant revenue will be lost.

Each piece must be cleaned, sorted, trimmed, and evaluated before it can be priced. Pricing depends on a combination of size, shape, color (both intensity and purity), and rarity.



Author Jim Clanin excavates a pocket of tourmaline and smoky quartz at the Cryo-Genie mine, near Warner Springs, San Diego County, California. Photo by Brendan M. Laurs.

THE MAKING OF A DIAMOND MINE: WHY EVERYONE CANNOT HAVE ONE

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Diamond deposits are rare occurrences that require specialized geologic and engineering expertise to discover and especially to develop into mines. They take the forms of primary kimberlite/lamproite deposits and secondary concentrations in alluvial deposits. These can be mined as open pits, underground operations, or even undersea. Diamond deposits are generally small to medium in size and may occur in remote and/or difficult-to-access locations. They are defined by the concentration, size, and quality of the diamonds, and whether they are in an environment where extraction costs are less than ore revenue. Many natural and technical considerations affect the balance of revenue and



Shown here is a kimberlite bulk sampling operation (large diameter drilling) at the DO-27 kimberlite, Northwest Territories, Canada, in March 2006. Photo by H. G. Coopersmith.

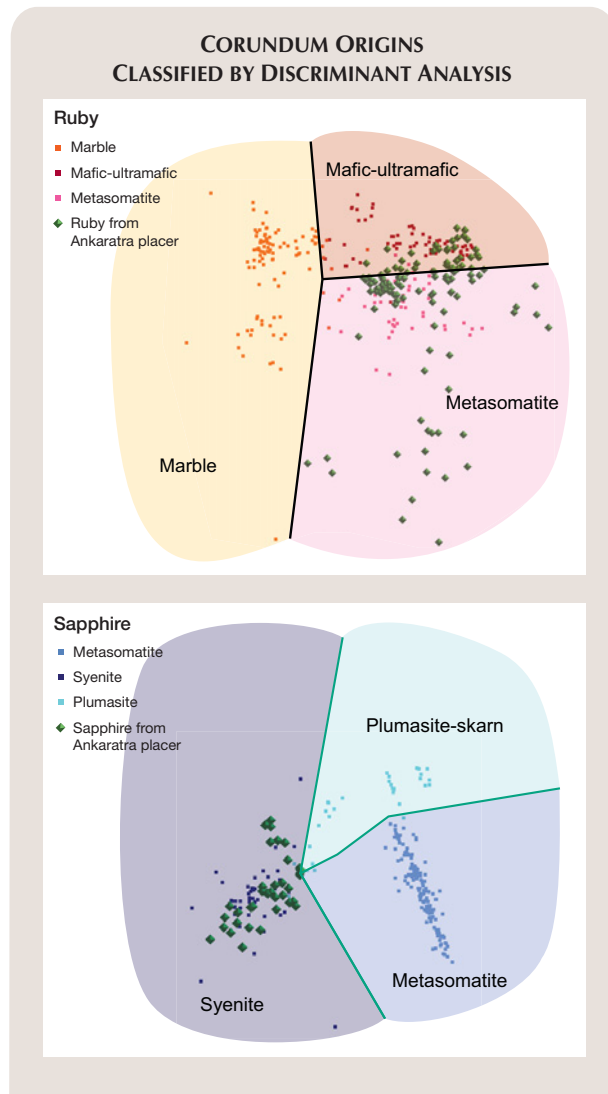
costs. Diamond distribution and size frequency distribution are highly dependent on the nature of the kimberlite and its primary emplacement and secondary distribution processes. A thorough and detailed understanding of the geology produces accurate modeling, which is essential in exploration through feasibility analysis, production, and eventually resource reconciliation. Diamonds are a purely accidental product of several unique geologic processes that form the first part of the puzzle. Mine discovery and feasibility include many factors that form the second part of the puzzle, and only rarely do all the factors align.

STATE OF THE ART IN THE FORMATION OF HIGH-VALUE COLORED STONES

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Whereas diamonds are mined by large international companies and cut and marketed through a well-established distribution network, most high-value colored stones are extracted by independent miners or small companies and sold through less-organized channels. Exploration and grading protocols for ruby, sapphire, emerald, tsavorite, tanzanite, and alexandrite are virtually nonexistent due to the lack of intense research efforts or standardized values on the international exchange. Grading the quality of diamonds on the basis of the 4Cs (color, clarity, cut, and carat weight) is universally accepted and there are virtually no provenance-dependent variations in commodity value. With colored stones, though, geographic origin is an important factor for determining price.

The trace-element (e.g., Cr, V, Ti, Mn, and Fe) and oxygen-isotopic composition of gems depend directly on the geological, physical, and chemical conditions of their formation. These



Discriminant analysis, based on oxide concentrations (Cr_2O_3 , FeO , Ga_2O_3 , MgO , TiO_2 , and V_2O_5) for the main types of gem corundum deposits worldwide, deciphers the origin of rubies (top) and sapphires (bottom) in placers associated with the Ankaratra alkali basalt field in central Madagascar.

include temperature, pressure, fluid composition, redox conditions, and the source of these minor elements. There are still many questions regarding the geology of high-value colored stone deposits, and further research on their genesis is necessary, as has been done on ruby in marbles, corundum in basalts, and Colombian emeralds. Although colored stones may occur in both metamorphic and igneous rocks, the most important primary sources are metamorphic. Deposits of Colombian emerald, marble-hosted ruby, tsavorite, and tanzanite are all evaporite-related, linked to metasedimentary platform carbonates at different geological periods. The association of evaporite-organic matter with black shale and carbonates plays a key role in the formation of

highly saline fluids in open hydrothermal systems such as those that formed Colombian emeralds (basinal and highly saline fluids). High-temperature fluids of appropriate composition in closed metamorphic systems can significantly mobilize the chemical elements required to produce gems, such as marble-hosted ruby in Asia (CO_2 -salty and sulfate-rich metamorphic fluids and molten salts) and tsavorite and tanzanite in the Neoproterozoic Mozambique Belt (sulfur-rich metamorphic fluids).

Rubies form in various types of metamorphic-metasomatic deposits: mafic-ultramafic rocks (M-UMR), desilicated pegmatites hosted by marble or M-UMR, and M-UMR dikes in marbles. The metamorphic origin of the marble-hosted ruby deposits of Tanzania is different from those of Central and Southeast Asia. Most of the Tanzanian deposits are linked to metasomatism of mafic dikes (amphibolite) injected into marbles (the Lukande, Greyson, and Kitwalo ruby deposits in the Mahenge district). The mafic dikes and the marbles were previously altered metasomatically by fluid percolation. The final product is the formation of a Mg-rich phlogopitite reaction zone at the contact of both formations. Rubies are concentrated in this zone or in the neighboring marble, or both. Sapphires occur in desilicated pegmatites in M-UMR as well as in magmatic environments such as alkali basalts, syenites, and skarns. Chemical classification of corundum using discriminant analysis of oxide concentrations (Cr_2O_3 , FeO , Ga_2O_3 , MgO , TiO_2 , and V_2O_5) of ruby and sapphire from primary deposits worldwide allows us to determine the most probable origin of corundum in placers. Rubies from alkali basalt placers in the Ankaratra plateau of central Madagascar have two main sources, M-UMR and metasomatites, while the sapphires are of magmatic origin (syenitic source).

Unlike Colombian emeralds, other types of emerald deposits are directly linked to:

1. The presence of pegmatites, aplites, or quartz veins intruding M-UMR or Cr-V-bearing sediments.
2. Pegmatitic pods in anorogenic granites such as at the Kaduna plateau in Nigeria, where the source of Cr is still debated.
3. Shear zones characterized by the absence of pegmatites where emerald is contained in phlogopitite or talc-carbonate host rocks (i.e., the Santa Terezinha de Goiás deposit in Brazil and the Swat deposit in Pakistan, respectively).
4. Regional metamorphic rocks, such as those in Austria (Habachtal), Egypt (Jebel Sikait, Jebel Sakara, and Umm Kabo), and South Africa (Leydsdorp), despite the presence of pegmatites (transformed to albitites).

The first of these genetic pathways is the most common. It is characterized by emeralds contained in Mg-rich micaceous rocks known as biotite or phlogopite schists. Generally the pegmatite and the adjacent M-UMR suffer intense fluid percolation and

metasomatism, which dissolves quartz in the pegmatite (which is transformed into a plagioclase of generally albite-oligoclase composition). The M-UMR is converted into the micaceous host rock to the emeralds. Yet the metasomatic processes are highly variable and depend on the P-T conditions, the timing and intensity of the regional deformation, and the extent of fluid infiltration. At Canada's Tsa da Gliza deposit, Be-bearing magmatic fluids from the neighboring granite continuously reacted with the Cr- and V-bearing UMR. Emeralds formed in aplite, pegmatite, and quartz veins surrounded by phlogopites. At the Sandawana deposit in Zimbabwe, the intrusion of pegmatites into the M-UMR, their shearing and boudinage, and their Na-K-Mg metasomatism were all coeval with regional deformation, and emerald formation was syntectonic. At the Ianapera deposit in Madagascar, two coeval emerald deposits are notable: (1) proximal, formed classically at the contact between the pegmatite and the UMR; and (2) distal, formed far from the pegmatite, in shear fractures developed in the M-UMR and filled by emerald-bearing phlogopites.

The genesis of alexandrite is directly linked to that of emerald. Alexandrite is found in placers (the Hematita deposit in Brazil, for instance) but also in primary deposits such as those in the Urals and Spain. The Cr-bearing chrysoberyl is generally associated with phenakite (Be_2SiO_4), which is stable at high Al_2O_3 activity and a rather low SiO_2 activity. A transformation of alexandrite and phenakite to emerald results from an increase in SiO_2 activity, expressed by the equation:



The stability fields of alexandrite and emerald correspond to those required for the formation of desilicated pegmatites (i.e., transformed by dissolution of quartz and crystallization of Na-rich feldspar). In this chemical domain, high Al_2O_3 activity would permit the formation of either alexandrite or corundum if the fluids were saturated with respect to corundum. The Poona deposit in Australia is the only known locality with a ruby, alexandrite, and emerald association.

MYSTERY DIAMONDS—FROM ALLUVIAL DEPOSITS

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Diamond deposits occur in three main types: alluvial, primary (or pipe), and coastal (marine). Before the discovery of kimberlite pipes as the primary source of diamonds, the origin of alluvial diamonds was not known. One theory held that diamonds grew in gravels and were biogenic in nature, since diamond is composed of carbon; some inclusions in diamond were interpreted as being composed of vegetable matter. After the discovery of kimberlite pipes, many alluvial deposits could be traced directly to these rocks, but many others could not, and their precise origin is still a mystery.

The major localities of alluvial deposits are:

1. *Southern Africa*, where the large Vaal-Orange (South Africa), Lunda–Western Kasai (Angola and Democratic Republic of the Congo), and Eastern Kasai (DRC) alluvial deposits can be traced to kimberlite pipes, but the Lichtenburg (South Africa) and Marange (Zimbabwe) deposits cannot.
2. *Equatorial Africa*, where the origin of alluvial deposits in the Central African Republic, northern DRC, Republic of the Congo, Cameroon, and Gabon remains a mystery.
3. *West Africa*, where most of the alluvial deposits in Sierra Leone, Guinea, and Liberia can be traced to kimberlite pipes and dikes, but the origin of diamonds in the Birim River alluvials of Ghana is still unknown.
4. *South America*, where some alluvial diamonds in Rondônia and Mato Grosso (both in Brazil) can be traced to kimberlite pipes, but the origin of most other alluvial deposits in Brazil, Guyana, and Venezuela has not been identified.
5. *India*, where the origin of most alluvial deposits, especially the Golconda deposits, cannot be traced.
6. *Borneo*, with alluvial deposits that cannot be traced to a primary rock and have an unfavorable geologic setting.
7. *Eastern Australia* (same comments as for Borneo).
8. *Canada*, where the origin of the Archean alluvial deposits at Wawa (Ontario) is still unexplained.
9. *The United States*, where alluvial diamond occurrences in California and the Appalachian Mountains remain a mystery.

Explanation of the sources of these mysterious deposits include (1) reversal of drainage, (2) primary rock not yet found, (3) primary rock not kimberlite and thus overlooked, and (4) a different theory of formation (e.g., subduction in eastern Australia and Borneo). None of these explanations is completely satisfactory, and the origin of many alluvial deposits is still unknown.

GEOLOGY, EXPLORATION, MINING, AND PROCESSING OF GEMS AND GOLD FROM PLACER DEPOSITS ON THE MUHUWESI RIVER, TUNDURU, TANZANIA

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Diamond, gold, and various colored stones are found in placer deposits within a delta-shaped basin at the junction of the Muhuwesi and Nampungu rivers near the southern Tanzanian

village of Muhuwesi. Granitic gneiss and granulite of the Usagaran Formation are the primary source rocks of the gold and colored stones, while the diamonds originated from Tertiary–Quaternary volcanic rocks that erupted through the Karoo Formation. The colored stones range from less than 0.2 g to more than 20 g, and good-quality diamonds weighing more than 50 ct have been found. The gold varies from fine dust to nuggets larger than 0.5 cm. Garnet and chrysoberyl are the most abundant gems, and they are used as pathfinder minerals during exploration.

In this swampy basin, trenching exploration using a backhoe is limited to depths of 3–4 m. The Dutch Banka drill is unsuitable because the core samples are too small. Mechanized bore-pile drilling can be used instead to penetrate through large gravel beds, and bulk samples of coarse material can easily be obtained from the large-diameter bailers. The drilling costs are half those of the Banka drill, while the results are much more efficient and accurate. The bore pile drill can be conveniently used as an exploration as well as semiproduction drilling machine for this type of operation.

Mechanized open-pit mining to expose the gem-bearing gravel beds that lie beneath the groundwater table (4–10 m) is too costly and inefficient because of the need to remove the sliding overburden and drain the groundwater. The problem can be solved by using a suction dredge to excavate waste tailings directly into the previously excavated open pit, in combination with a fully equipped mineral processing machine for recovering the final concentrate.

Gravity concentration processing uses a sorting jig to separate coarse-grained gems and gold from associated minerals. The coarse-grained minerals are concentrated on the jig floor, whereas the fine-grained products are discarded as undersized tailings.

This series of jigs is being used in the Tunduru area of Tanzania to separate coarse-grained minerals—including gems and gold—from the fine-grained material. Photo by R. Limsuwan.



Fine-grained gold and small gems can be recovered from these tailings with many practical processing methods.

Entrepreneurs should have a clear understanding of an area's geologic details to insure that mining and processing methods match the scale of the deposit.

GEM POCKETS IN PEGMATITES—A WORLDWIDE STUDY AND COMPARISON

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To locate gem pockets, we must consider the morphology of pegmatite systems with their individual veins and structures. Gem-bearing pegmatite and greisen systems also deserve comparison with other ore deposits. Many of their pocket formation mechanisms and structural features are similar. An igneous rock contains a series of structures and vein types, such as miarolitic pockets in granite; pegmatites in the form of pods; chamber pegmatites (Ukraine, Finland); ascending “drops” of pegmatite (South Platte, Colorado); chimneys, mushroom formations, and stoves (“baking ovens”); fracture fillings in granite or pegmatite; and brittle to ductile wallrock relations. The content and quality of gem species in pockets varies considerably, adding to the unpredictability.

Delicate, undisturbed, relatively thin pegmatite veins (around 1 m thick), such as those at Stak Nala and Biensapi in Pakistan and the Himalaya–San Diego dike system in California, formed in conditions that led to a large number of pockets, with an abundance of high-quality gem crystals 3–20 cm long in the first and second pocket generation. Commonly there are 2–4 generations of gem species in a pocket, and many individual pegmatites have several generations of pockets (e.g., the Karelia beryl mine). Thicker veins with similar characteristics may have pockets localized along thin fracture lines: Virgem da Lapa, Brazil; Darra-i-Pech, Afghanistan; and Alabashka, Russia. Much larger veins—such as at the Stewart mine (California) and Mount Mica (Maine) in the United States, Mawi in Afghanistan, Urucum and Morro Redondo in Brazil, Mokrusha in the Russian Urals, and some pegmatites in the Haramosh/Shigar/Braldu areas of Pakistan—may have significant amounts of very high-quality gem material in sections or single cavities. Adjacent cavities may have a completely different mineralogy. Large pegmatites, due to their scale and mining exposures, may have a less visible and longer multistage complex formation of pockets, ovens, and chimney structures.

Namibia's Erongo Mountains host large pegmatite veins containing gem tourmaline-rich pockets on the Davib Ost farm. Nearby, in the Erongo granite, is a completely different type of mineralization: thin fissures may open into pegmatite veins or pockets/chimneys up to dozens of meters long and a few decimeters wide, with a vertical segregation of gem aquamarine, black tourmaline, quartz, hyalite opal, fluorite, jeremejevite, and other minerals. More hydrothermal-like veins are found at Chumar

Bakhoor in Pakistan and Mount Xuebaoding in China, yielding aquamarine. A detailed study of the Malmberget iron mine in Sweden revealed that many of its structures, fractures, pockets, and crystallizations are similar to those of pegmatites.

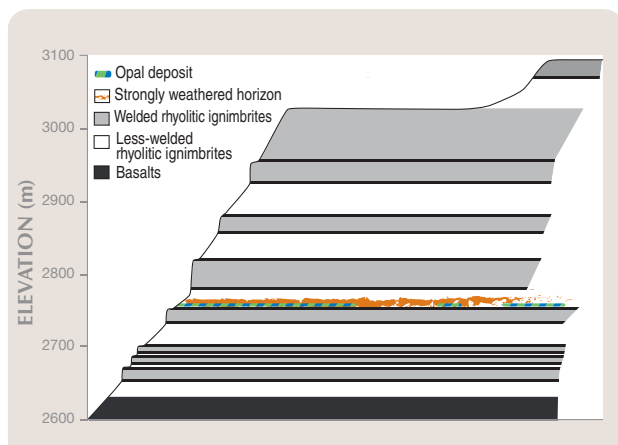
AMAZING PLAY-OF-COLOR OPALS FROM WOLLO, ETHIOPIA—TOWARD A GENETIC MODEL

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The area around Wegel Tena in Ethiopia's Wollo Province is becoming a major producer of opal. Some specimens are very large and display amazing play-of-color. A November 2010 field trip confirmed at least 10 distinct deposits, with many more likely to be discovered in the future. All the deposits occur at the same strongly weathered stratigraphic level in a thick Oligocene volcano-sedimentary series. Each deposit consists of a flat lens about 10–100 m long and about one meter thick, where opal occurs as irregular masses cementing clay gravels or filling in cavities. Many biological features have been observed, such as plant fossils within specimens and opal filling in root-like cavities. We also observed many sedimentary characteristics within the volcanoclastic strata, such as desiccation features, rounded clay-gravels, and conglomerates. This evidence suggests that the opal formed during an episode of weathering in the Oligocene period, in between volcanic emissions.

Opal deposits in Ethiopia's Wollo Province formed within a strongly weathered horizon of ignimbrite (partially fused volcanic ash).



DIAMONDS AND CRATONS—DOES THE RELATIONSHIP HOLD FOR THE CANADIAN DEPOSITS?

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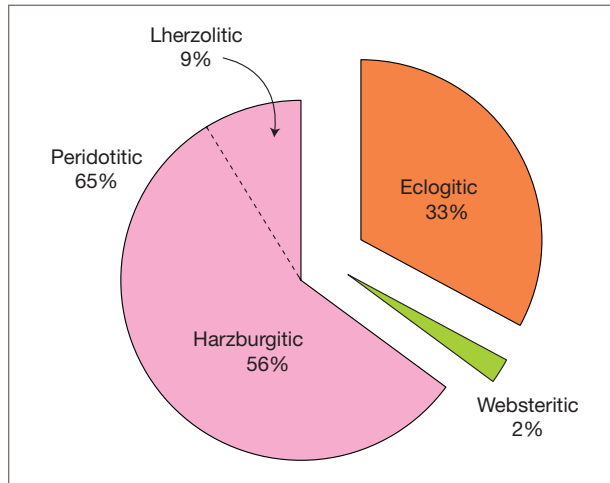
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Diamonds and Cratons. The exclusive association of primary (kimberlite- or lamproite-hosted) diamond deposits with long-term stable continental cores, termed *cratons*, was established empirically in the 1960s and became known as Clifford's Rule. In its original version (Clifford, 1966), Clifford's Rule defined cratons as those cores that have remained stable for at least 1.5 billion years; later revisions pushed this age standard back to the end of the Archean eon, 2.5 billion years ago. Through a combination of geophysical data and geochemical studies—employing mantle xenoliths (mantle-derived rock fragments) and inclusions in diamonds—it was recognized in the 1980s that the ultimate cause for this link between diamonds and cratons lies in unusually deep-reaching lithospheric keels beneath cratons, extending about 200 km into the convecting mantle.

The lithosphere, or rock-sphere, is the nonconvecting outermost shell of our planet, and includes the crust and top portion of the upper mantle. Formed during intense extraction of partial melts in an Archean mantle much hotter than the present one, the residual rocks that make up these lithospheric mantle keels are buoyant, making them stable over time and almost devoid of heat-producing radioactive elements. Consequently, the relatively cool and deep-reaching mantle roots beneath cratons are the only areas on Earth where the lithosphere reaches into the diamond stability field. Today we know that more than 99% of the world's diamond production ultimately derives from subcratonic lithospheric mantle, with only very rare diamonds coming from even greater depth. The role of kimberlite and lamproite magma is to provide a transport vehicle, picking up diamonds during their passage through the deep lithospheric mantle and rapidly conveying them to the earth's surface.

From the study of inclusions in diamonds, three suites of rocks have been identified that may act as a substrate for diamond formation in the lithospheric mantle: peridotite, eclogite, and websterite. Peridotite, named for its high olivine (peridot) content, constitutes the bulk of the upper mantle. Eclogite is the high-pressure equivalent of basalt, the volcanic rock that covers about two-thirds of the earth's surface beneath the oceans. The presence of eclogite in the lithospheric mantle appears related to the closure of ocean basins during past plate tectonic cycles and the associated process of subduction. The websteritic inclusion suite is loosely defined as being compositionally intermediate between peridotite and eclogite. Websteritic diamond sources may have multiple origins.

Silicate and oxide mineral inclusions recovered from more



This chart shows the proportion of diamonds of peridotitic, eclogitic, and websteritic suites, based on the study of some 3,000 inclusion-bearing diamonds from mines worldwide. The subdivision of peridotitic diamonds into a harzburgitic and a lherzolitic (including 1% websteritic diamonds) paragenesis is based on garnet inclusions only.

than 3,000 diamonds derived from worldwide sources demonstrate that peridotite is the most important source rock of diamond. Peridotite accounts for 65% of inclusion-bearing diamonds, followed by eclogite (33%) and websterite (2%). Based on garnet inclusion chemistry, Gurney (1984) established that the vast majority of peridotitic diamonds belong to the harzburgitic paragenesis, a subclass of peridotite characterized by strong depletion through melt extraction (a process in which easily fusible components are removed, leading to low concentrations of elements such as Al, Ca, and Na). Despite being the most important diamond source, harzburgite is a rare rock type in the earth's mantle. It is almost exclusively restricted to Archean lithospheric mantle, where on average about 10% of peridotitic garnets sampled are harzburgite derived.

Analyses of diamond's carbon isotopic composition and nitrogen content have yielded new insights into the actual processes surrounding diamond formation. Diamond appears to form during redox reactions where either carbonate is reduced or methane is oxidized to elemental carbon. Both processes are documented to be widespread, but preliminary data suggest a shift from methane oxidation to carbonate reduction as the preferred mode of diamond formation over geologic time.

Diamonds in Canada. Following the 1991 announcement of the discovery of diamonds at Point Lake and the subsequent exploration and mining rush, Canada emerged as an important producer in 1998 with the opening of the Ekati mine. As of 2011, approximately 700 kimberlites have been discovered across the Canadian Shield. Four mines are operational, and several mining projects are in advanced stages.

Among Canada's cratons, the Slave Province has remained the most important diamond source economically. Its three currently

operational mines are located in the Slave Province—in the Lac de Gras area (Diavik and Ekati) and at Snap Lake—and in the Superior Province (Victor mine in the Attawapiskat Field).



This map (after Kjarsgaard, 2007) shows kimberlite fields and clusters in Canada.

Current mines are located in the Slave Province—in the Lac de Gras area (Diavik and Ekati) and at Snap Lake—and in the Superior Province (Victor mine in the Attawapiskat Field).

operational mines—Diavik, Ekati, and Snap Lake—will produce about US\$23 billion in diamonds over their life spans of typically around 20 years. Based on isotopic studies, diamond formation in the Slave Province occurred in two main phases: between about 3.5 and 3.3 billion years ago for peridotitic diamonds, and about 2 billion years ago for eclogitic diamonds. Peridotitic diamonds account for most of the production of the three current mines, which are located in the Central and Southern Slave; eclogitic diamonds predominate in the currently defunct Jericho mine (Northern Slave). Comparative studies of the Slave and Kaapvaal (South Africa) cratons show that the central and southern portion of the Slave lithospheric mantle has experienced less-obvious secondary modification (“mantle metasomatism”). This observation likely explains the overall less-resorbed nature of Diavik, Ekati, and Snap Lake diamonds (compared to, for instance, the typical De Beers Pool production from South Africa).

Canada’s largest craton, the Superior Province, is host to the Victor mine at Attawapiskat and the advanced Renard project in the Otish Mountains of Quebec. Victor produces diamonds of spectacular quality, and its spatial association with the 1.1-billion-year-old midcontinent rift suggests parallels to the Cullinan mine (formerly known as the Premier) in South Africa, where younger generations of lherzolitic and eclogitic diamonds formed in association with and subsequent to the major Bushveld magmatic event. Preliminary studies on diamonds from the Otish Mountains indicate a “normal” cratonic suite of predominantly peridotitic origin.

Over the last few years, an abundance of diamondiferous kimberlites have been discovered in the northern and western

parts of Canada’s third major craton, the Churchill Province. In addition, Saskatchewan’s Fort à la Corne kimberlite field, located on the small Sask Craton, is approaching economic feasibility thanks to a detailed understanding of its geologically complex diamond distribution. Kimberlites in the Buffalo Hills of Alberta pose a challenge to the rigorous interpretation of Clifford’s Rule that specifies Archean lithosphere as the precondition for primary diamond deposits. At Buffalo Hills, several of the approximately 50 known kimberlites carry significant quantities (up to 0.5 ct/tonne) of overall very high quality diamonds. Yet this area, the Buffalo Head Terrane, does not constitute a craton in the strict sense, due to its intense reworking about 1.9 billion years ago. Similarly unconventional diamond deposits have recently been identified, including the Amazon Shield in Brazil, where the diamondiferous Pimenta Bueno and Carolina kimberlites are emplaced in an area stabilized only 1.8 to 1.2 billion years ago.

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COLORED STONE AND PEARL IDENTIFICATION

GEOGRAPHIC ORIGIN DETERMINATION OF COLORED GEMSTONES

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Colored gemstones such as ruby, sapphire, emerald, and Paraíba-type tourmaline may achieve higher prices when associated with a specific geographic pedigree. Therefore, dealers and collectors increasingly turn to gemological laboratories for country-of-origin analysis. To determine provenance, a laboratory must be knowledgeable about the gems’ geologic formation conditions and types of host rock, crystal growth features, and mineralogical and gemological properties. When the geologic conditions of the primary rock are very similar among several different localities, however, the gemstones’ properties may overlap, rendering origin determination difficult or impossible. Laboratories must meet

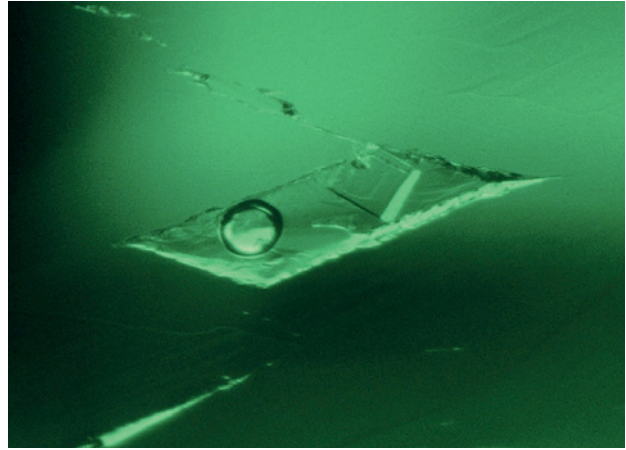
The author collects reference samples in situ from a sapphire mine in Australia (Rubynvale, Queensland). Photo by Terry Coldham.



this complex challenge by extending their observations and analytical capabilities to identify multiple features that yield diagnostic patterns to distinguish between similar sources.

Studies of gemstones from known deposits have been carried out for decades. Inclusions, spectra, trace-element chemical composition, and oxygen-isotope tracers are used to constrain source parameters. But which techniques are most effective for each type of stone? In conducting origin determination, laboratories must characterize gems by nondestructive (or micro-destructive) testing methods, and must also consider the following:

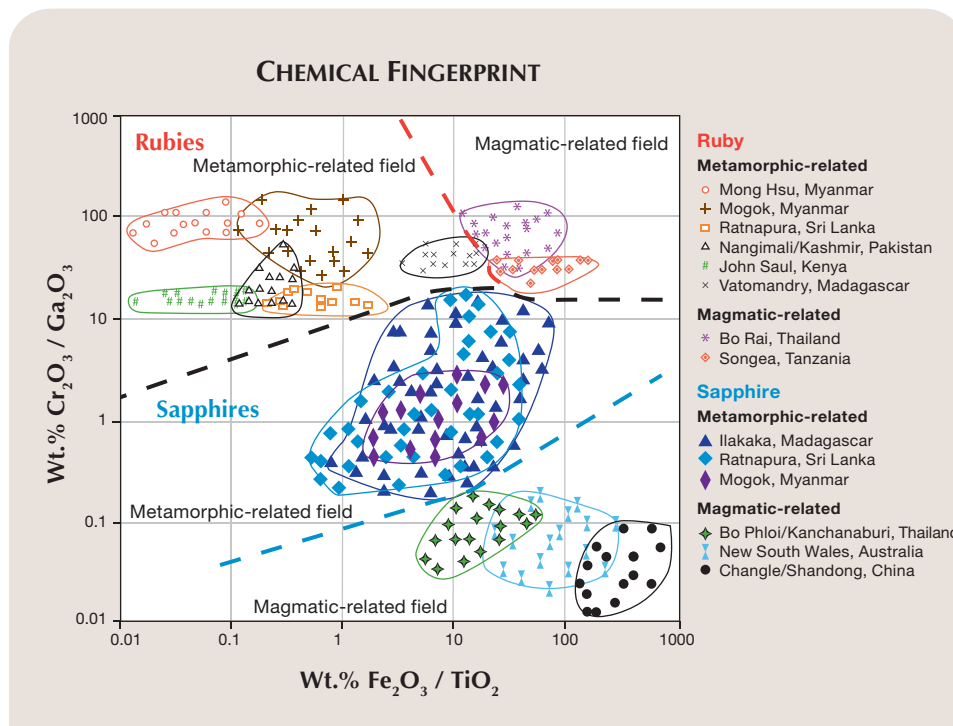
1. A database of properties from samples of known origin requires a reference collection containing numerous representative stones, including those from the newest sources. To ensure authenticity, the samples should ideally be collected from the host rock and/or directly from the producing mine.
2. Internal features (inclusions and growth structures) may help determine a gem's geologic environment, and may provide enough evidence to clearly separate different sources. For example, zircon clusters indicate the host corundum may be from Madagascar, and three-phase inclusions in emerald are characteristic of a Colombian source.
3. UV-Vis-NIR absorption spectra may directly or indirectly reveal the geologic environment (i.e., metamorphic, metasomatic, or magmatic origin of corundum) by their Fe-related features. Some features related to mineral inclusions or molecular vibration due to water can be detected by infrared



Inclusions can help distinguish the geologic environment in which a gem was formed. This three-phase (solid, liquid, gas) inclusion is characteristic of emeralds from Colombia. Photomicrograph by John I. Koivula; magnified 40x.

spectroscopy, making it useful for determining provenance. For example, unheated Mong Hsu (Myanmar) ruby may show dominant absorption in the mid-infrared region that is related to diaspore inclusions. Also, unheated magmatic-type sapphires tend to show strong bands related to Ti-Fe-OH vibrations; these are absent from metamorphic-type sapphires.

4. From a chemical standpoint, patterns of major, minor, and trace elements can reveal a sample's geographic origin.



This diagram shows the chemical fingerprinting of ruby and blue sapphire from a variety of sources.

Certain elements (e.g., Fe and Cr in ruby, and Fe and Ga in sapphire) can be used to establish chemical “fingerprints” of different geologic environments. EDXRF spectroscopy is a rapid technique that is readily available in most gemological laboratories, but it provides limited data compared to more advanced (and expensive) methods such as LA-ICP-MS. Accurately measuring a wider range of characteristic trace elements increases the possibility of reliably identifying geographic origin using two-dimensional trace-element chemical fingerprinting and multivariate statistical analysis. Metamorphic- and magmatic-related corundum can be separated on the basis of $\text{Cr}_2\text{O}_3/\text{Ga}_2\text{O}_3$ versus $\text{Fe}_2\text{O}_3/\text{TiO}_2$. The origin of emeralds can be narrowed down by plotting $\text{Cs}_2\text{O}+\text{K}_2\text{O}$ versus $\text{FeO}+\text{MgO}$ to separate Santa Terezinha (Brazil), Kafubu (Zambia), and Sandawana (Zimbabwe) sources from Panjshir (Afghanistan), Itabira–Nova Era (Brazil), Cordillera Oriental (Colombia), Kaduna (Nigeria), and Swat (Pakistan) deposits. Paraíba-type tourmaline from Brazil, Mozambique, and Nigeria can be differentiated by plotting Ga+Pb versus Cu+Mn and also Cu+Mn versus Pb/Be.

A combination of internal characteristics, absorption spectra, and chemical data obtained by LA-ICP-MS is effective for separating gems from different geographic origins.

AUSTRALIAN OPAL NOMENCLATURE AND ASSESSMENT

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Precious opal (i.e., opal that shows play-of-color) has long been considered one of the most difficult gems to describe, categorize, and appraise. Work on a suitable nomenclature system began at the Gemmological Association of Australia (GAA) in 1995, and the system was published in *Australian Gemmologist* two years later (Smallwood, 1997). At the time of its publication, the nomenclature was supported by all the Australian opal and jewelry industry associations. While CIBJO adopted the system and other overseas associations entered into initial discussions on it, further international acceptance was limited by a lack of effective promotion.

The GAA's standardized nomenclature is based on the different genetic types of precious opal. The present authors propose a new approach to grading precious opal that is based on components of the accepted nomenclature. A simplified terminology clarifies existing industry standards while adhering to both industry practice and the established nomenclature.

The aim of this new approach is to introduce three easily understood categories by which precious opal from any source can be graded, evaluated, and marketed. The 3 C's—*Category*, *Color*, and *Cut*—determine the quality grade. Each category is

evaluated using a point system that quantifies the various quality features of precious opal. *Category* defines the type of precious opal: *Natural type 1–opal*, *Natural type 2–boulder opal*, and *Natural type 3–matrix opal*. *Color* describes the range of quality color features. *Cut* describes the style and quality of cut. Based on this evaluation system, each precious opal can be assigned one of five quality classifications: *Exceptional gem*, *fine gem*, *gem*, *commercial gem*, and *promotional gem opal*. This will promote confidence and understanding of precious opal at all levels, from wholesale to retail and on to the consumer. This combination of opal nomenclature and grading systems provides a complete and universal system of terminology for use in applications such as appraisals and certifications. Myths and mistakes will be eliminated, fostering global appreciation of Australia's national gem.

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AN LA-ICP-MS STUDY OF LAVENDER JADEITE FROM MYANMAR, GUATEMALA, AND JAPAN

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Jadeite jade with colors variously termed *lavender*, *mauve*, or *purple* is among the most prized for jewelry and decorative arts. Studies on the mineralogy of these jades and the source of their lavender color have ascribed the color variously to Mn, Fe, and Ti (Chen, 1999; Ouyang, 2001), and more specifically to Fe^{2+} -O- Fe^{3+} (Rossman, 1974) and to Mn^{3+} in synthetic samples (Nassau and Shigley, 1987). Samples in the American Museum of Natural History collections were studied by electron microprobe and LA-ICP-MS to assess their geochemistry and potential compositional correlations with lavender color and source.

In a sample from the Myanmar's central Jade Tract, relatively intense lavender-colored growth zones showed clear highs in MnO_T (up to 0.15 wt.%; T = total) and low FeO_T (<0.03 wt.%) in nearly pure jadeite (Jd). Jadeite without lavender color, verging on gray or green, typically had <0.02 wt. % MnO_T and 0.01–0.7 wt. % FeO_T in crystals with Jd_{99-88} . Nepheline was a trace phase.

A pale lavender cabochon from Nansibon, Myanmar, proved to be a mix of jadeite and omphacite, with low MnO_T and FeO_T (both ≤ 0.1 wt.%) in Jd_{99-85} ; FeO_T also was low (≤ 1.2 wt.%) in (and for) omphacite. Cymrite was a trace phase.

A lavender jadeite from La Ensenada, Guatemala, occurred in pumpellyite-jadeite and contained ≤ 0.06 wt. % MnO_T and <0.02 wt. % FeO_T in crystals with Jd_{100-98} . “Colorless” jadeite from this locality generally had ≤ 0.01 wt. % MnO_T and comparable FeO_T . Mn was partitioned into the gray pumpellyite in amounts at least three times that of the jadeite in these jadeites. Grossular and albite also were present.

Pale lavender jadeite from Kotakigawa in Japan was Jd_{100-90} with ≤ 0.05 wt.% MnO_T and 0.1–0.5 wt.% FeO_T , whereas the “colorless” crystals contained <0.01 wt.% MnO_T and <0.1 wt.% FeO_T . Pectolite inclusions were common.

A comparison of some trace-element concentrations in the jadeite samples is shown in the table.

This study confirms Mn as the lavender chromophore in nearly pure jadeite with relatively low Fe. Although the valence has not been determined, Mn^{3+} is a likely candidate. Mineralogy and trace elements can be used to distinguish lavender jadeites from these sources.

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Trace-element composition (in ppm) of lavender jadeite from various localities.

Element	Jade Tract, Myanmar	Nansibon, Myanmar	La Ensenada, Guatemala	Kotakigawa, Japan
Li ^a	27–60	60–90	50–80	11–34
B	<2	10–20	0.1–4	30–60
Sr	~3 (lavender) 60–150 (other)	10–50	1–6	80–160
Zr	27–60	60–90	50–80	11–34

^a All with no portioning with color.

SPECTRAL DIFFERENTIATION OF NATURAL-COLOR SALTWATER CULTURED PEARLS FROM *PINCTADA MARGARITIFERA* AND *PTERIA STERNA*

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The popularity of colored cultured pearls has grown dramatically over the last 30 years. Saltwater cultured pearls (SWCPs) from *Pinctada margaritifera* and *Pteria sterna* are among the most intensely colored in the market today. Their various combinations of body-color and overtone result in a wide variety of color appearances.

New research into their spectral characteristics has led to proposed criteria for identifying which of the two mollusks is the source of a cultured pearl as well as for separating natural- from treated-color specimens. We performed photoluminescence (PL) spectroscopy with green laser excitation in the UV-Vis-NIR region (0.7 nm resolution) on 40 natural-color SWCPs from both mollusks, covering a wide range of colors.

Six color-inducing absorption features were observed in natural-color SWCPs from *P. sterna*:

- A continuous absorption that gradually cut through the visible region with a maximum in the near-infrared (at about 820 nm).
- An absorption from the UV-to-blue portion (330–460 nm, consisting of two bands at 330–385 nm and 385–460 nm).
- Three absorption features at ~405, 460, and 495 nm, and one in the red at ~745 nm.

These same absorptions were also found in natural-color SWCPs from *P. margaritifera*, with an additional band at ~700 nm. Small absorptions at 530, 585, 625, and 680 nm were recorded in natural-color SWCPs from both mollusks, but they had little impact on their coloration.

To our knowledge, only the cause of the 405 nm band is known to date: it is a type of uroporphyrin. The exact color of these cultured pearls is due not to a single absorption, but to the relative intensity of several absorptions. The vast majority of natural-color SWCPs from *P. margaritifera* show an absorption at ~700 nm that has not been observed to date in *P. sterna* natural-color SWCPs. Samples of the latter—even white ones—show a very pronounced PL peak at 620 nm (often accompanied by two others at 650 and 680 nm) that is faint or absent from the spectra of *P. margaritifera* samples. PL bands at ~475 and 530 nm were observed in all colors of SWCPs from both mollusks.

Acknowledgments: The authors thank Perlas del Mar de Cortez, Guaymas, Mexico—as well as Ecole de Greffe (school of pearl farming techniques), Rangiroa, French Polynesia, and the ADEQUA program (Service de la Periculture) and IFREMER (French Research Institute for Exploration of the Sea), French Polynesia—and Centre de Recherche Gemmologique for providing the study samples.

PEARL IDENTIFICATION—A PRACTITIONER'S PERSPECTIVE

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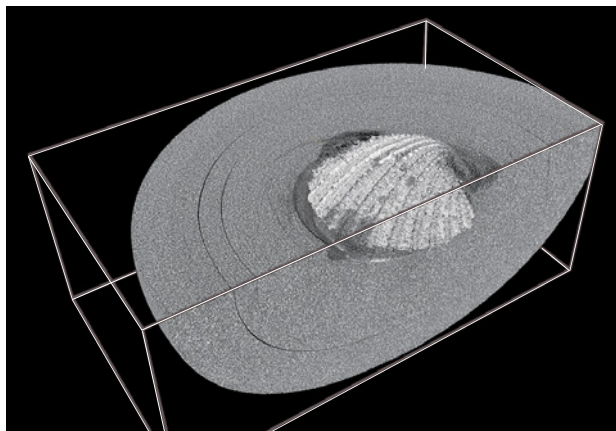
Due to the highly specialized nature of pearl identification, most gemologists do not readily recognize the ongoing challenges in areas such as detecting certain natural and cultured varieties, treatments, and mollusk species. While these issues have long been

compounded by the secrecy that has generally been endemic within the pearl industry, the trend toward greater openness has led to numerous breakthroughs. At the same time, embracing the increasingly expensive identification technologies has placed financial pressure on laboratories.

The current battery of testing methods includes everything from macro and microscopic observations to spectroscopy, chemical analysis, fluorescence, and various forms of X-ray imaging.

1. Visual observation distinguishes nacreous and non-nacreous pearls, reveals the condition of the surface, and determines whether a sample has been subjected to polishing, heavy or light working, or dyeing. Viewing into drill holes may reveal a shell bead or the characteristic warm centers of a natural pearl from *Pinctada radiata*. The non-nacreous surface structures of some pearls may also help determine their source (e.g., scallop, clam, pen, or Melo).
2. Raman spectroscopy can determine whether the surface layers are composed of calcite or aragonite, the nature of the coloring elements, and the presence of some dyes. UV-Vis spectroscopy may help establish whether the color is natural or due to a treatment process, and if luster enhancement has recently taken place.
3. Chemical analyses provide particularly useful information in distinguishing between saltwater and freshwater origin, and in some instances they can identify specific localities within those origins. Chemical data also assist in the detection of dyes and coatings.
4. X-ray fluorescence observations may help separate saltwater from freshwater origins, while UV fluorescence is often useful in determining the type of mollusk.
5. X-ray imaging, still the bedrock of pearl testing techniques, is used to detect the presence of a shell bead and show growth characteristics.

Separating Natural and Cultured Pearls. As growth techniques continue to improve, the separation of natural from non-bead cultured pearls, both saltwater and freshwater, becomes particularly challenging. Traditionally, this identification has involved the interpretation of microradiographic images. For more than eight decades, these images have been recorded on fine-grained industrial X-ray film and examined with magnification (using a 10x loupe, microscope, and custom-built apparatuses). With the need for finer detail and higher-resolution images, combined with the trade's demand for speed and digitized data, laboratories have moved toward high-resolution real-time microradiography and, more recently (when necessary), micro-CT X-ray imaging. Even with these advances, though, other forms of data collection are often necessary.



*This 3D-constructed image (from a micro-CT X-ray scan) shows a scallop shell in the center of a 19.06 grain natural pearl produced by *P. maxima* in Australian waters. Image by Nick Hadland, Nikon Metrology.*

A case in point is the separation of U.S. freshwater natural pearls from Chinese freshwater cultured pearls. Their microradiographic structures are sometimes similar, requiring detailed chemical analyses to assist in the separation. A new problem is the separation of natural from cultured conch pearls, a situation made more difficult by the color instability of conch pearls to X-rays.

Treatment Issues. Pearls may be treated in a variety of ways. The best-known method, though still something of a mystery, is the bleaching of akoya cultured pearls. The pretreatment to this bleaching, known as Maeshori treatment, has become popular with other cultured pearl varieties as a stand-alone process to temporarily enhance luster. UV-Vis spectroscopic techniques have

Chinese non-beaded freshwater cultured pearls (here, 8–12 mm) and U.S. freshwater natural pearls often have similar microradiographic structures, and detailed chemical analyses are required for this separation. Photo by K. Scarratt.



been developed to detect this treatment.

Most dyes can be readily spotted through visual observation, with Raman and chemical analyses providing confirmation. More difficult to uncover are subtle coatings, and UV imaging has proved particularly useful in this regard.

The working of natural pearls has been around for hundreds of years, particularly with natural blister pearls. But with the high prices being paid for exotic natural pearls from the Melo volutes, the practice of working a baroque Melo pearl into a perfectly round specimen has become endemic.

Mollusk Identification. Apart from rare cases, mollusk identification was not a concern as recently as 10 years ago. Today it is an important aspect in determining whether the pearl is cultured or has been treated in some way. An example of this importance is in the identification of natural or cultured pearls from *P. margaritifera* through its unique reflectance spectra when compared with other pearls that have been treated to a similar appearance, or identifying various *Pteria* species and their sometimes unique natural microradiographic structures.

NATURAL-COLOR TANZANITE

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The violet to blue variety of the mineral zoisite took the gem industry by storm after its discovery in 1967. Since then, tanzanite has become one of the four most popular gemstones sold at retail. It is well known that the vast majority of tanzanite in the market owes its color to a relatively low-temperature heating process that transforms the original brown zoisite into tanzanite.

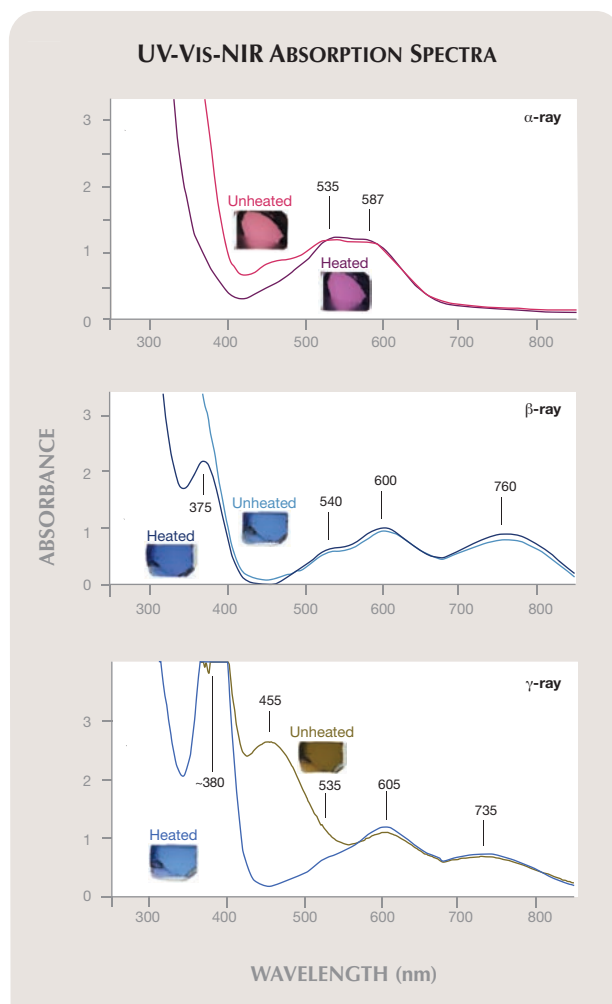
It is also known that a small amount of zoisite comes out of the ground already blue. It was generally thought that this was an extremely small percentage (<1%), but the author's trip to the tanzanite mines in October 2009 revealed a higher proportion, estimated at more than 10%. In all, nearly 300 natural-color tanzanite samples were collected directly from the mine-run at the TanzaniteOne facility and from the group's sightholders. All samples were tested using standard gemological instruments, and advanced analytical tests were performed on a core subset that were fashioned into crystallographically oriented cubes for oriented and polarized UV, visible, near-IR, mid-IR, and Raman spectroscopy. Controlled heating experiments were conducted on oriented cubes and rough, and all data were collected again to record the changes that took place.

The brown color of zoisite correlated to two specific absorption features: an increasing general absorption continuum toward the UV and a broad band centered at approximately 455 nm. The intensity of these absorptions determined whether the zoisite had an overall brown appearance or a brown coloration along only one of the three pleochroic directions. The violet to blue coloration is attributed to V^{3+} in an octahedral coordina-

tion. The elimination of both browning absorptions during heating creates a transmission window at approximately 450–480 nm, which changes the observed color along the gamma pleochroic direction from brown-yellow or brownish greenish yellow to slightly greenish blue. Little to no change was recorded in the absorptions attributed to vanadium.

The change in color of brown zoisite to tanzanite has been attributed by past researchers as a conversion of V^{4+} to V^{3+} . The

Heating of zoisite produced little to no change in V^{3+} absorptions. Along the alpha pleochroic direction a shift in the absorption edge was recorded, while additionally along the beta direction a band at 375 nm became apparent. The most significant change took place along the gamma direction where the shift in the absorption edge revealed another band at ~380 nm and the combined removal of the 455 nm band created a transmission window in the blue region of the spectrum, causing this pleochroic hue to change dramatically from a brown-yellow or brownish greenish yellow to slightly greenish blue.



observed character and annealing behavior of the two browning absorptions in the present study has sparked further investigations into other potential causes, involving lattice defects and color centers. In addition, the data recorded during this study expands that previously documented for natural-color tanzanite.

EXPERIMENTAL TREATMENTS INVOLVING DYE AND HEAT FOR CHINESE FRESHWATER CULTURED PEARLS, AND THEIR DETECTION WITH RAMAN SPECTROSCOPY

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Ten nonbeaded Chinese freshwater cultured pearls (button shapes, 4.11 × 2.71 mm to 4.41 × 2.88 mm) were subjected to five different treatments (i.e., two samples for each process). The effects on appearance and durability were observed, and the samples were also analyzed by Raman spectroscopy. Their original color was white, and the presence of Newton rings (visible with a gemological microscope) suggested they had been previously bleached.

The treatment processes involved:

1. Heating in an electric oven at 250°C for 15 minutes.
2. Dyeing with a hair toner (Redken 03B) for 30 minutes.
3. The same process as in (2), plus heating as described in (1).
4. Dyeing with a hair colorant (Wella Koleston 5/77) for 30 minutes.
5. The same process as in (4), plus heating as described in (1).

The color changes and their effects on UV fluorescence are listed in the table.

Viewed with a microscope, the heated cultured pearls from process (1) showed cracks and brownish color spots around the drill hole. The toner (2) caused a brown rim at the drill hole and “splash” effects beneath the surface. Additional heating (3) led to cracking and surface peelings. The colorant (4) caused a brown rim at the drill hole, and subsequent heating (5) produced cracks with color residues.

Raman analyses were obtained for five of the cultured pearls at the SSEF laboratory using 514 nm laser excitation. All spectra were corrected by a square or cubic baseline subtraction, to eliminate the increasing luminescence and make the pigment peaks visible. Apart from the dominant calcium carbonate vibrational peaks, the samples dyed with toner and colorant revealed distinct Raman peaks between 1800 and 1100 cm⁻¹ that were smoothed out in the dyed

and heated cultured pearls. The untreated cultured pearl showed very weak peaks at approximately 1525 and 1130 cm⁻¹ due to natural color pigments (Karampelas et al., 2007).







Photoluminescence testing with 514 nm laser excitation revealed a general luminescence in all the samples, with a maximum at ~4000 cm⁻¹ (or 648 nm). The untreated cultured pearl showed weak luminescence, ~3–5 times lower than in the treated samples. The luminescence of the heated-only sample was so strong that the aragonite peaks nearly disappeared, and the signals could only be measured by lowering the laser beam's intensity.

Readily available toners and dyes can be used to alter the color of cultured pearls, either alone or in combination with heating. Heating by itself is also effective. Each of the treatments caused damage and changed UV fluorescence reactions. Raman spectroscopy revealed distinct spectral differences between the treated and untreated cultured pearls.

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Effects of treatments on Chinese freshwater cultured pearls.

Treatment		Color	UV fluorescence (long-/short-wave)
Untreated		White	Strong blue/ weaker blue
(1) Heat		Bronze	Pinkish/yellowish in parts
(2) Toner		Brownish gray	Blue in parts/ weaker reaction
(3) Toner + heat		Brownish bronze	Inert to pink in parts/same reaction
(4) Colorant		Brownish gray	Blue in parts/ weaker reaction
(5) Colorant + heat		Grayish brown	Pink in parts/ weaker reaction

DURABILITY AND SAFETY TESTING OF LEAD GLASS-TREATED RUBY AND BERYLLIUM-TREATED SAPPHIRE, AND ENVIRONMENTAL IMPACT ASSESSMENTS

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Tens of thousands of carats of ruby and sapphire recently sold in the world market appear to have been treated using complicated techniques that may involve chemical additives. Many parties have raised concerns about the stability and safety of these treated stones with normal wear, as well as the environmental impact of the treatment processes involved. Researchers from the Gem and Jewelry Institute of Thailand, a public organization, have collaborated with experts to conduct environmental impact monitoring of Pb-glass and Be-diffusion treatments, as well as standard testing on the stability and safety of the products of both. The three-stage sequential extraction procedure suggested by the European Standards, Measurements and Testing Program (formerly the Community Bureau of Reference, or BCR) was selected for this study.

Three forms of metals (acid-extractable, reducible, and oxidizable) were tested. Chemical analyses of the leached solutions and observations of alterations within the samples were carried out at each stage of the experiment by ICP-MS. Lead concentrations in the solution extracted from rubies treated with Pb-glass were much lower than the maximum allowable concentration. Be concentrations in the solution extracted from Be-treated sap-

phires were below the detection limit (~ 0.01 ppm). Thus, we concluded that these treated stones are safe for normal wear. In the durability testing, the gemological properties of both treated groups remained unchanged, though the treated rubies appeared to have lower transparency after prolonged testing.

We conducted further analyses of Pb and Be concentrations in the form of respirable particulates at several home-based factories in Chanthaburi Province. The results showed that lead particulates were only emitted when the furnace gate was opened, with the highest concentrations recorded within the first 10 minutes. The amount of Be particulates was much lower than the maximum allowable concentration in air.

While our studies have shown very little or no impact from these treatment processes, we recommend an efficient ventilation system to help separate the treatment areas from living areas in a home factory.

ARCHAEOGEMOLOGY OF PERIDOT

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The Red Sea island of Zabargad, also called St. John's Island, is perhaps the world's oldest and most famous source of gem olivine, or peridot. Although early accounts attest to knowledge of its existence, and much has been written about Zabargad's geology and modern mine workings, the ancient site was not located until recently. In June 2010, archaeological evidence of occupa-



At left is a biconvex oval peridot ringstone (18.0 × 16.0 × 5.0 mm, Greek, 2nd century BC), engraved with the head of a maenad and mounted in a modern metal setting. At right is a convex oval peridot ringstone (8.5 × 7.4 × 3.1 mm, Hellenistic, mid-1st century BC), possibly depicting Ptolemy XII. Both intaglios are heavily abraded. Courtesy of the Ashmolean Museum, University of Oxford (left), and the Michael C. Carlos Museum, Emory University, Atlanta, Michael J. Shubin collection (right).

tion associated with mining activity was identified by author JAH, including about 150 surface pits, peridot fragments, ruins of dwellings, a well, and pottery sherds dating from the Hellenistic era (323–31/30 BCE) into the Roman Imperial period (after 30 BCE). The archaeological finds correlate with those excavated from the ancient trading center of Berenike, which is situated near Ras Banas on Egypt's southern Red Sea coast, the nearest port to Zabargad Island. Both Zabargad's peridot mine and Berenike were founded by Ptolemy II Philadelphus, who ruled Egypt from 285 to 246 BCE. Under Roman occupation, Berenike rose to prominence as an international entrepôt, exporting peridot and other gems from local Egyptian mines while importing gems from distant sources, including India, Sri Lanka, and possibly points farther east, through the mid-6th century.

A survey of ancient carved peridots in private and museum collections reflects the rising fortunes of Zabargad and Berenike through the 1st century CE. The survey reveals a narrower timeframe of production and fewer surviving examples than previously supposed. Most peridots of this period were cut from relatively large crystals, and all exhibit exceptional clarity and a saturated yellowish green color without any trace of a brownish cast. Although archaeological and textual evidence of Graeco-Roman peridots originating from Zabargad appears compelling, other sources cannot be excluded summarily. In *Natural History* (77 CE), Pliny the Elder describes different sources for several other gems with varietal names that may be peridot, and the gems examined by the author LT are strikingly similar to specimens from other sources, especially Pakistan and Myanmar (Burma).

A provenance study on peridot is in progress at GIA. Samples collected from the ancient mine site on Zabargad and from other sources—including Saudi Arabia, Pakistan, Sri Lanka, Myanmar, and China—may reveal salient data points for future comparison against ancient carved peridots. A definitive determination might also shed light on the mysteries concerning the origins, circulation, and use of peridot in the ancient world.

RESEARCH AND IDENTIFICATION OF NATURAL AND TREATED NEPHRITE IN CHINA

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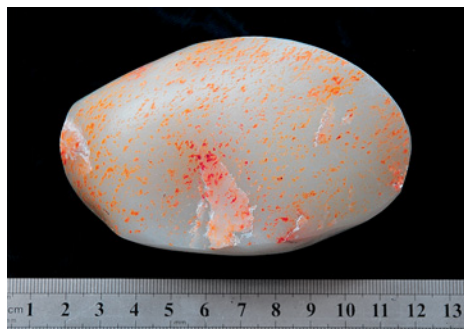
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Nephrite (particularly Hetian jade) is a treasured gem material in China. Its use extends back 7,000 years and is closely connected to Asian culture. Primary deposits are distributed mainly in the Kunlun Mountains in Qinghai Province and the Xinjiang Uygur Autonomous Region. Secondary deposits are found nearby in alluvial settings or desert areas.

With China's rapid economic development, nephrite has become even more popular, and this has been accompanied by sharply rising prices. In addition to the material from Qinghai and Xinjiang, various white and colored nephrite jades from other countries, as well as treated and imitation nephrites, are appearing in Chinese markets. Due to the rarity and value of white nephrite pebbles that display a surface coloration, various imitations and treated-color products (dyed, heated, or otherwise enhanced) are also appearing.

To both guide and support the nephrite jade market, the NGTC has organized a research team to perform a systematic investigation of this material. This involves both field studies of the nephrite sources and laboratory examination of samples using a variety of techniques. The samples are characterized on the basis of their morphology, surface microstructure, spectroscopic features (visible, infrared, and Raman), and chemical composition. The surface microstructures of thousands of samples have been analyzed using high-resolution digital imaging techniques. We have found that natural nephrite pebbles can be recognized by their surface microstructures, which are apparently caused by geologic processes such as glacial or water transport and weathering. For example, chatter marks caused by glacial abrasion and plucking processes occurred on the surfaces of the pebbles. The natural coloration on the pebbles' surface is formed mainly by iron-containing secondary minerals that occur along grain boundaries. Surface-treated samples can be distinguished by differences in surface microstructures, as well as by spectroscopic and chemical data.

The natural nephrite pebble on the left (95 × 78 × 38 mm) shows typical surface microstructures and orange-yellow spot-like coloration. The artificial nephrite pebbles on the right (8–35 g) were manufactured from low-quality nephrite; some have been treated to add surface coloration.
Photos by Yong Zhang.



NEW TECHNOLOGIES AND INSTRUMENTATION

THE IMPACT OF THE CHOICE OF ILLUMINATION IN THE WHOLESALE BUYING, SELLING, AND GRADING OF GEMSTONES

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Members of the gem community often demand very specific types of illumination, depending on the gem material they are dealing with and whether the application is related to buying, selling, or grading. This study examines what a trade person at the wholesale level expects from a light source, in terms of color/hue and overall appearance, when illuminating a gemstone. The testing involved 43 individuals and was conducted on-site at offices, trade fairs, and auctions. The illumination consisted of a tabletop lamp with four different compact 18-watt fluorescent lamps and a 35-watt incandescent halogen lamp. The fluorescent lamps varied from 6500 to 3000 K in correlated color temperature (CCT), while the halogen lamps with enhanced CCT covered a range of 4700–3500 K. The color rendering index (CRI) of the light sources was between 90 and 98. The traders were asked to view their own gems in each of the five light sources and give their preferences.

While the main focus was on colored stones, cultured pearls and fancy-color diamonds were evaluated as well. Fluorescent lamps of 6500 K are uncommon today, and even fancy-color diamonds are typically illuminated by 5800–5400 K light. Only blue sapphires are presented in the 6500 K light traditionally used for diamonds, but very often in combination with 5800 K lamps. Rubies, on the other side of the color spectrum, are typically displayed with incandescent lamps of 3200–2800 K or fluorescent lighting of 5400–3200 K.

The results supported a well-known axiom of the colored stone trade: “The best light source is the one that gives you the best selling results.” This often differs from the official recommendations of the CIE International Commission on Illumination, which specifies a color temperature for gem materials in the 6500–5500 K range. It also appears that the practical illumination of the trading environment is very different from the standardized grading used at gem laboratories. Now that LED and OLED technologies—with their specific characteristics, spectrum, color of light, and CRI—have added to the available options, the evaluation of gem colors must be considered “in a new light.”

ADVANCING THE UNDERSTANDING OF LUMINESCENCE IN GEM MATERIALS

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The luminescence of gem materials is used to address an array of identification problems in gemology. In fact, luminescence spectroscopy was the technology that made it possible to identify HPHT-treated near-colorless diamonds. However, the cause of this visible-light emission in many gems often remains a mystery to gemologists.

Luminescence must be preceded by an excitation, which in gemology is usually ultraviolet or visible-light absorption. Hence, interpreting this phenomenon is even less straightforward than interpreting absorption itself (which is the cause of color in most gems), as it represents only the first step in the emission process. Some causes of luminescence are well known, such as Cr³⁺ in a variety of gems or some common color centers in diamond. For the most part, though, the causes of luminescence have not been explored systematically. Nevertheless, they can usually be determined by analyzing the emission and excitation spectra generated by luminescence spectroscopy, often combined with trace-element analysis.

The better-known (but not necessarily most common) causes of luminescence in gems include Cr³⁺, Mn²⁺, and other isolated transition metal ions, as well as molecular groups, color centers (extended and point-defect), and organic materials. Recent studies we conducted have demonstrated the complex nature of the luminescence in some gems. We investigated samples of these materials with several varieties of luminescence spectroscopy. We first used emission and excitation spectra on a traditional permanent-regime spectrometer (the Jobin Yvon Fluorolog). Some clues as to the time behavior were obtained with a far more complex custom-built transient-regime spectrometer using femtosecond laser excitation to observe emissions lasting only a few nanoseconds. In diamonds, in particular natural type Ib crystals, the luminescence can be dominated by unidentified broad bands, whereas more common, easier-to-identify emissions (e.g., H3, NV⁻) remain a minority component. In opals, the classic green luminescence is due to uranyl (UO₂²⁺) but its transient behavior is somewhat surprising. The blue component in opal luminescence is intrinsic, due to two surface-related defects.

The origin of orange luminescence in sapphire has never been systematically investigated. It appears in all colors of corundum, natural or synthetic. It is almost always present in Be-diffused corundum, and therefore probably related to a hole center. It is very short-lived (5 ns on average), in contrast with the long-lived Cr³⁺ emission.

ADVANCED GEM CHARACTERIZATION

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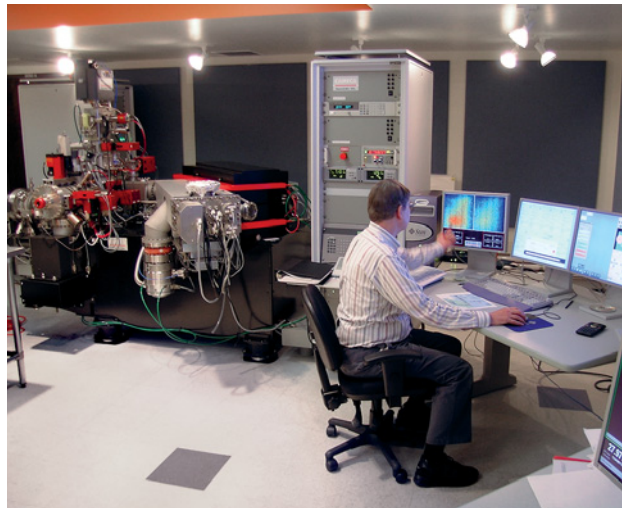
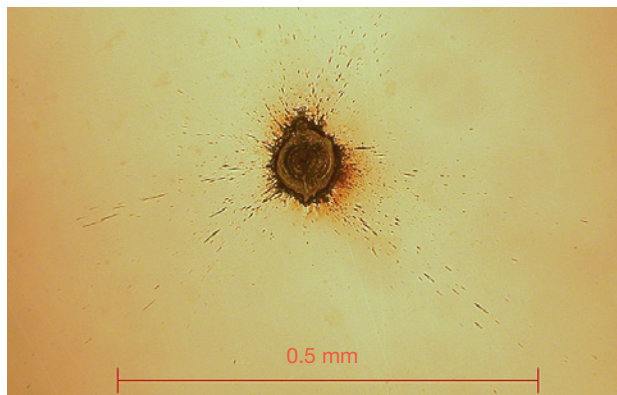
As clever minds combine an ever-increasing menu of high-tech methods in the quest to enhance the properties of both natural and synthetic gems, the challenges of gem characterization continue to grow rapidly. Gemology has adopted new methods to keep pace.

Techniques considered advanced a decade ago—such as infrared, Raman, X-ray fluorescence, and photoluminescence spectroscopy, as well as LA-ICP-MS—are now routine analytical tools in well-equipped gemological laboratories. Trace-element analyses at the parts per million level are now at the forefront of determining locality of origin and treatments. New methods now being used in academic and industrial laboratories will become increasingly important in gemological labs as the technology applied to gem treatments rapidly advances.

Established tools remain important, though. Infrared spectra can be used to identify phases (including X-ray amorphous phases), detect the presence of organic oils and resins in stones, classify diamond type, and identify certain minor and trace constituents of minerals that may reveal clues to their origin or treatments. Raman spectra are also used for phase identification. Because the beam can be focused as small as a micrometer in diameter in laboratory-grade instruments, Raman spectroscopy has become the method of choice to identify small inclusions in stones. The availability of large libraries of spectra makes this a powerful technique for nondestructive phase identification (even of organic components).

Visible-range spectroscopy remains a primary tool for studying color in minerals. Combined with chemical analysis, it can determine which metals cause color, in which oxidation states the metals occur, and even the site in the crystal where they

This minute crater on the surface of a pink sapphire was produced by LIBS analysis. Photo by G. R. Rossman.



A nanoSIMS is a powerful analytical instrument that can detect both trace elements such as beryllium diffused into corundum and the isotopic compositions of the stone. Photo by Brendan M. Laurs.

occur. Such information can assist in geographic origin studies.

Luminescence reveals much about the growth history of minerals, and several of these methods have found important gemological applications as well. Luminescence helps identify certain treatments and is of particular use in separating natural and synthetic diamonds. Thermoluminescence testing responds to radiation damage induced either by nature or by laboratory treatment. Unfortunately, this test is destructive and will remove color from most samples.

Laser-ablation methods (LA-ICP-MS and LIBS) have opened up a whole new range of quantitative analyses of most elements in the periodic table. In addition to providing basic information about the chemical composition of a gem, these analyses are often of great use in establishing geographic origin, while leaving only a tiny crater on the gem's surface. Secondary-ion mass spectrometry (SIMS and nanoSIMS), an ion-beam method, provides highly sensitive chemical analysis of selected elements and also gives isotopic compositions (leaving craters of just 20 to 0.1 μm in diameter). This technique is also well-suited for obtaining chemical depth profiles of coatings.

X-ray methods have evolved from a primary method for phase identification to a tool for nondestructively detecting and analyzing a number of minor components, and now digital X-ray methods are used to obtain images of the internal structure of pearls.

This author anticipates that other new tools will become commonplace in the years ahead. Electron paramagnetic resonance (EPR) is a particularly sensitive analytical tool for detecting certain metals, color centers, and radiation damage centers at low concentrations. This could be particularly useful in the examination of color centers in diamond and the changes these centers undergo with heat and other treatments. Unlike ther-

oluminescence, EPR does not destroy radiation-induced color. Analysis of specific isotopes is now frequently applied in academic research, but has seen comparatively little use in gemology. Oxygen isotopes show a wide range of variation in geologic systems. Analysis of oxygen isotopes has already been established as a powerful method to distinguish emeralds and corundum from different geographic origins. Argon isotopes, meanwhile, have played a major role in proving that some samples of red andesine from Asia have been treated.

APPLICATIONS OF FLUORESCENCE IN GEMOLOGY

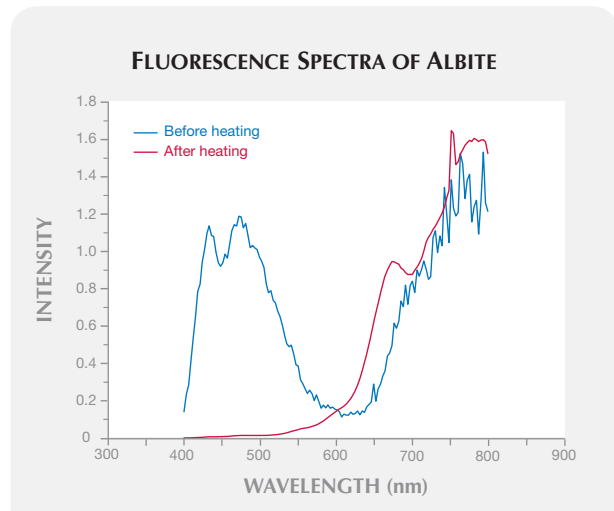
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Fluorescence, or luminescence, is used extensively in mineralogy to investigate both intrinsic and extrinsic atomic crystalline defects, including their nature and relative concentrations (Finch and Klein, 1999). Although the technique has seen limited use in gemology, it provides insights into genesis, paleochemistry, and paleotemperature that can potentially differentiate natural, treated, and synthetic gems (Pagel et al., 2000). Following are applications of both continuous-wave and time-resolved luminescence as we have applied them to gemology.

Data were obtained through imaging and wavelength spectroscopy, and by studying luminescence as a function of both wavelength and luminescence lifetime time-resolved photoluminescence. We are investigating the utility of X-ray excited optical luminescence (XEOL), which uses X-ray luminescence from a synchrotron source, both as a function of the lifetime and the energy of the incident X-rays. We are also using time-resolved fluorescence in the form of fluorescence lifetime imaging microscopy (FLIM) to study fluorescence structures within gems and minerals. A mature methodology in biochemistry and cell biology (Becker, 2005), FLIM shows exciting potential for mineralogy and gemology.

These methodologies have applications in determining gem provenance and detecting treatments and synthetics. Defect patterns in the form of color centers and luminescence centers in gems can be used to identify, for example, characteristic growth and chemical signatures. Differentiating between natural and treated color continues to challenge gemologists. Luminescence offers a powerful nondestructive methodology with great potential to assist in this endeavor.



Wavelength resolved emission spectroscopy shows distinct differences in a sample of albite before and after heat treatment.

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Shipwrecked!

DEBATE CENTER

Captain

Dr. Brian Natrass Managing Partner,
Sustainability Partners

First Mate

Susan M. Jacques President and CEO,
Borsheim's Fine Jewelry and Gifts

Passenger List

Tom Cushman Managing Director,
Richfield Investor Services

Richard Drucker President, Gemworld International

Martin Rapaport Chairman, The Rapaport Group

Dr. George Rossman Professor of Mineralogy,
California Institute of Technology

The 5th International Gemological Symposium ended with a fast-paced 90-minute debate on sustainability, “conflict” gems, and fair trade. Like previous Symposium debate centers, this forum had a theme: A shipwrecked luxury liner had stranded a group of gem industry leaders on a remote island, and their only means of rescue was to resolve the conflict between ethical business practices and the realities of the marketplace. As the castaways exchanged opinions and ideas, a microphone captured pointed comments and questions from the audience.

Moderator Susan Jacques started the debate by asking about the effectiveness of trade sanctions against Myanmar and Madagascar, as well as their impact on local miners.

The first to respond was panelist Richard Drucker, publisher of *The Guide*, which tracks wholesale gem prices. He said that despite the sanctions imposed on Myanmar since 2008 by the United States’ Tom Lantos Block Burmese JADE Act, exports were up 12% last year, more than half of them going to the

Chinese market. “The problem is that it’s not working . . . The miners are the ones that are actually getting hurt. The military junta is still in power, and it’s just becoming a worse situation.”

Madagascar-based gem dealer Tom Cushman cited a similar situation in that nation. After a 2009 coup replaced the country’s democratically elected president, its AGOA (African Growth and Opportunity Act) duty-free export status was suspended. “The gangsters that are running Madagascar now are completely unscathed by those sanctions,” Cushman said. “Do sanctions work? Maybe in Washington. They may get somebody reelected.”

Martin Rapaport weighed in, adding, “The idea that the government is in charge of your ethics—I don’t agree with that at all. The bottom line is that *you* are responsible for what you buy. You have the economic power. . . . There has to be an economic incentive for evil people to stop being evil, not just negative punishment.”

The idea that the government is in charge of your ethics—I don’t agree with that at all.

– Martin Rapaport

Dr. Brian Natrass, who has worked with Nike and Starbucks to achieve sustainability goals, agreed. “It’s always seemed to me that sanctions are like a bludgeon, and we need to be a lot more articulate and a lot more creative.”

Jacques steered the debate to her native Zimbabwe, where the government brutally evicted miners from the Marange diamond fields in 2008. She acknowledged a “personal bent” against allowing her own retail store to purchase Marange diamonds, even though their export was approved a year ago by the Kimberley Process Certification Scheme.

From the audience, Douglas Hucker asked the panel what trade members could do as individuals to meet the goals of sustainability. Natrass suggested going after the “low-hanging fruit”

in manufacturing and retail operations, specifically in the areas of energy, waste, and water. “Those pay money. Those are tangible.

It always seemed to me that sanctions are like a bludgeon, and we need to be a lot more articulate and a lot more creative.

– Dr. Brian Natrass

to know what’s good and what’s just lip service, because if we put a little sticker on it we’re going to sell more product? Is this a marketing thing, or are we really just doing the right thing?”

Jacques was quick to uphold the trade’s altruism. “I don’t believe it’s all about money,” she said. “I think that many good, honest people want to do the right thing, even if they get less money.”

Rapaport replied that an entire industry cannot be expected to be altruistic unless there is some economic incentive. “Do you have an ethical responsibility to your shareholders, or to the people of Zimbabwe?”

Drucker turned to silicosis, a deadly lung disease that afflicts gemcutters and manufacturers of lead glass–filled rubies (particularly beads). He said that while most gem cutters and individuals would be willing to pay more for safely enhanced beads, companies purchasing large volumes of them would not.

Cushman elaborated on the fair trade concept. “Fair Trade with capital letters is owned by the Fair Trade Labeling Organization, and you’ve got to get them to sign off on your deal. And they’re very experienced at doing agricultural products, but they’re not very good with our sorts of things. . . . Fair trade with small letters is the kind of trade most of us are going to do, unless you want to give some group in Germany 3% of your gross

to say, ‘Yeah, you’re ok.’”

Cushman added, “If you need to pay somebody to let the world know you’re honest, perhaps you should wonder why they don’t think you’re honest to start with.”

Rapaport, describing fair trade as a unique selling proposition for the jewelry industry, said, “We don’t sell products, we sell feelings.”

That’s why you’re seeing Wal-Mart and Starbucks focusing so much effort in that area: because there is an immediate financial pay-back.”

Drucker, noting the growing number of organizations now involved in fair trade labeling, asked, “How are we as an industry going



Martin Rapaport (middle) proposes economic incentives rather than sanctions in promoting fair trade. Left to right: Dr. Brian Natrass, Dr. George Rossman, and Tom Cushman. Photo by Kevin Schumacher.

Dr. George Rossman replied, “But you also need a policeman to back up the feeling. You need the technology to ultimately be able to tell whether or not your retailer is telling the truth.”

Asked about gemological research efforts to identify a diamond’s country of origin, Dr. Rossman said, “It’s a long way off in terms of country of origin. With treatments, a lot of progress has been made with natural versus irradiated, but it’s not all there. . . . It’s going to take time, it’s going to take effort.”

Several audience members expressed frustration with media coverage and a desire to cast the industry in a more positive light. Cushman, speaking on behalf of a Madagascar-based sustainable

Dr. Chris Wellbourn listens to the debate on sustainability and corporate responsibility. Photo by Kevin Schumacher.



mining initiative called Art Miners, replied, “If you would like an opportunity to join us, give me some money. I’ll give you some PR. You can tell your newspaper you’re doing good work in Madagascar. . . . You’re giving education to people who didn’t have any, you’re giving opportunity to people. Harry Winston’s dead—there’s room at the top of our industry, and there’s no reason they can’t start in Madagascar.”

Jacques acknowledged the publicity efforts of the “acronym” trade organizations but urged the audience to use social media to

In our situation with our industry, we’ve got hundreds of countries, we’ve got thousands of miners, mostly in Third World countries. I think the challenge for us is much, much greater than finding [an ethical] source for lumber or coffee.

– Richard Drucker

finding a source for lumber or coffee.”

From the audience, Bev Hori related the story of a Starbucks coffee mug that sold so well the company had to double its order. “What they didn’t realize was that to fulfill that order, workers had to work double shifts back-to-back. Without intending to, they were causing worker abuse. What I learned from that is that

tell the story. Drucker added, “It’s going to be a lot more difficult in our industry. . . . Home Depot buys from a source, from a country where they get their lumber. In our situation with our industry, we’ve got hundreds of countries, we’ve got thousands of miners, mostly Third World countries. I think the challenge for us is much, much greater than



Bev Hori describes how corporate actions can have unintended consequences for artisanal workers. Photo by Kevin Schumacher.

you have to ask the questions, and let your vendors know that you care about the unintended consequences.”

Fellow audience member Kirk Root emphasized personal responsibility. “Each person here has the ability now in the 21st century to react personally, and right away.” With the power of social media, he added, “each one of us now has the ability to speak immediately and positively to deal with this.”

Natgrass wrapped up the debate with words of encouragement for the gem and jewelry industry. “I think we have favorable winds blowing for us. You deserve to be congratulated, and you’re ready to move.”

Stuart D. Overlin



DIAMOND IDENTIFICATION

LENGTH-TO-WIDTH RATIOS AMONG FANCY SHAPE DIAMONDS

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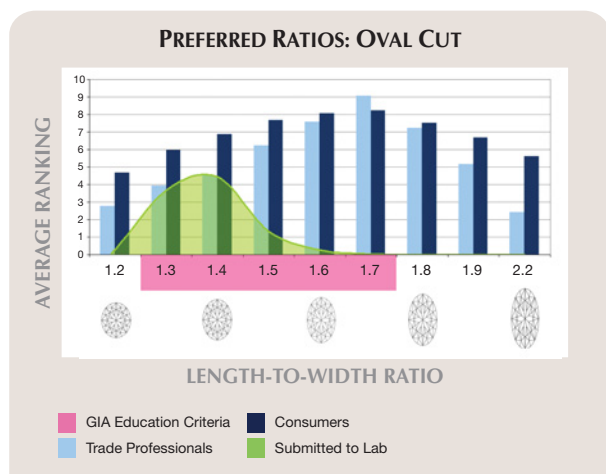
Evaluating cut in diamonds with fancy shapes is inherently more challenging than evaluating round brilliants because of the great diversity of cutting styles. Some parameters are unique to certain shapes, such as the degree of incision in a heart cleft, while others, such as length-to-width ratio, are common to most fancy shapes.

The length-to-width ratio is derived by dividing the diamond's length by its width. This ratio is an indicator of whether the outline is narrow (a higher ratio) or wide (a lower ratio). Fancy shape diamonds are commonly cut with certain ratios that primarily reflect the shape of the original rough, durability considerations, and occasionally perceived consumer preferences.

GIA conducted a survey in 2009 to assess personal preferences in the length-to-width ratios of fancy shapes. Images of four shapes—emerald, pear, marquise, and oval—with various lengths and widths were presented to 19 trade professionals and 25 consumers. The opinion results were compared to the “best” ratios taught by GIA educators and the distribution of length-to-width ratios of diamonds submitted to the GIA’s laboratory. Overall, consumers and trade professionals preferred narrower shapes than those being submitted to the lab.

Increasing length-to-width ratios for brilliant styles (oval, marquise, and pear) can limit the combinations of angles that

This histogram of length-to-width ratios for oval cuts compares opinions of trade professionals and consumers with the distribution of diamonds submitted to GIA’s laboratory. The range of recommended ratios taught by GIA Education is highlighted in pink for comparison.



produce pleasing light return. Some jewelry manufacturers also believe that narrower stones are more likely to incur damage during the manufacturing process or normal wear—especially susceptible are the points of thin-girdled pear or marquise shapes. The cutter, meanwhile, must consider the original shape of the rough and what it can economically yield. These concerns could skew the distribution of diamonds (as seen in the lab) toward shapes that are wider than those actually preferred by consumers or trade professionals.

We conclude that the trade should not be discouraged from cutting narrower stones when the opportunity exists, as long as these ratios are not combined with thin girdles.

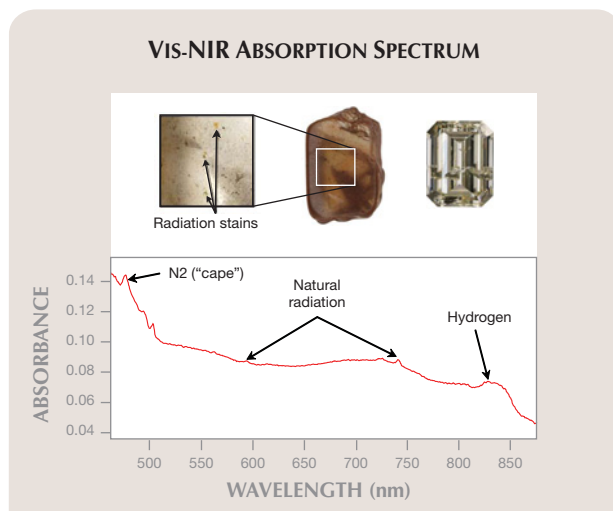
HYDROGEN-RICH DIAMONDS FROM ZIMBABWE WITH NATURAL RADIATION FEATURES

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GIA, Carlsbad

Over the last five years, diamonds originating from eastern Zimbabwe have sparked considerable controversy. Concerns over the potential “conflict” status of stones from the large Marange alluvial deposits in particular have resulted in export bans, smuggling, and limited disclosure of such diamonds in the marketplace. Some diamond samples from eastern Zimbabwe recently became available for study, and their properties are very interesting.

Gemological observations and spectroscopic data were collected from 26 diamonds (17 rough and nine faceted) from eastern Zimbabwe to characterize their identification features. The stones weighed 0.96–19.40 ct and were colorless, light yellow, or greenish yellow. All the rough diamonds and some of the faceted stones also showed greenish or brownish hue modifiers resulting from radiation damage, observed as green and brown stains on natural surfaces. UV-Vis-NIR absorption spectroscopy indicated that the yellow color was caused by “cape” diamond defects (N3 and N2), with the greenish and brownish overtones resulting from a combination of radiation-related (GR1, 595 nm, H3, and H4) and hydrogen (563 and ~834 nm) defects. Infrared absorption spectra further revealed that all of the Zimbabwean diamonds were type Ia with abundant B-aggregated nitrogen defects, except for one colorless stone that was type IIa. Most samples showed somewhat variable but significant IR absorption at 3107 cm⁻¹ caused by high concentrations of hydrogen-related defects. This combination of hydrogen- and radiation-related defects in cape yellow diamonds is uncommon, and could prove to be a useful identification feature for Zimbabwean diamonds.

Color-origin determination for diamonds with greenish hues produced by radiation has always been difficult for gemologists because of similarities in lattice defects between naturally and artificially irradiated samples. Since the eastern Zimbabwe deposits became prominent a few years ago, GIA has seen a



This 5.82 ct rough diamond crystal from eastern Zimbabwe is covered in brown and green radiation stains. It was cut into a 2.67 ct Fancy Light brownish greenish yellow diamond that showed a combination of cape-, hydrogen-, and radiation-related spectral features.

noticeable increase in the number of hydrogen-rich yellow and greenish yellow diamonds with radiation-related features submitted for identification reports. Consequently, it is critical that laboratories be able to separate natural-color from artificially irradiated diamonds. Comparing naturally irradiated Zimbabwean diamonds to similarly colored samples known to have been artificially irradiated reveals many similarities, but also a few important differences that make their separation possible in most cases.

RECENT STUDIES OF COLORED DIAMONDS FROM ARGYLE

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The color in pink and brown diamonds tends to lie along lamellae, which has long been taken to suggest that the colors result from plastic deformation of the crystal lattice. But how do the characteristics of the two colors differ, and what do they reveal about the cause of the colors?

This study involved an examination of four rough pink and brown-pink diamonds from the Argyle mine in Australia. Combinations of both pink and brown parallel lamellae occurred together in some stones, and commonly multiple sets of crystallographically aligned slip planes were present. These slip planes were especially prominent as fluorescence features seen with a confocal microscope when the diamonds were excited by 488 nm light.

Visually, though, in all the diamonds examined the color

banding appeared angled to these slip planes. This “illusion” was caused by the progressive weakening and strengthening of color along parallel planes. In some instances, curved banding was produced. Nitrogen concentrations appeared to affect the susceptibility of slip or the defects produced, as evidenced by a specimen containing two sets of colored lamellae corresponding to growth horizons. The pink diamonds generally had low concentrations of nitrogen (less than 100 ppm in mixed A and B forms), whereas the brown-pink stones typically had higher nitrogen concentrations with dominant B forms.

Birefringence strain analysis using a Metripol instrument indicated that pink and brown regions were generally associated with less strain than colorless zones.

Photoluminescence spectroscopy with 633 nm laser excitation revealed an emission line at 661 nm for the pink diamonds and one at 710 nm for the brown-pink stones. These emissions were polarized on one plane, presumably perpendicular to the direction of slip: very strongly for browns and weakly for pinks.

Brown color in type II diamonds has been reported to be associated with vacancy clusters (Avalos and Dannefaer, 2003), and this correlation has also been found in type I browns from the Argyle mine.

An interpretation of the above observations is that a sequence of two or more slip events is necessary to produce the pink defects, whereas a single event is sufficient to produce brown. It is these defects, most likely incorporating an impurity atom, that interact with vacancy clusters to produce the electronic energy levels required for the absorptions that cause the colors.

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Pink and brown graining is seen here in the polished face of a 0.6 ct rough Argyle diamond. Photomicrograph by J. G. Chapman.



EVIDENCE OF AN INTERSTITIAL 3H-RELATED OPTICAL CENTER AT 540.7 NM IN NATURAL DIAMOND

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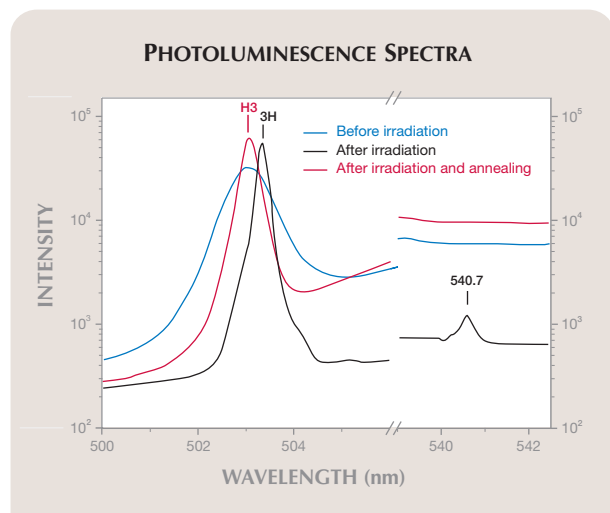
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Features resulting from radiation damage are important to the fundamental study of point defects in diamond. The primary products of radiation damage are vacancies and interstitials. Vacancies in both their neutral and negative charge states have been extensively investigated, but only relatively recently have detailed experimental studies been carried out on interstitials. The 3H and H3 defects have zero-phonon lines (ZPLs) that are very close to each other: 503.5 and 503.2 nm, respectively. While there has been some confusion among gem testing laboratories in the reading of these ZPLs in photoluminescence (PL) spectra, the two defects have very different vibronic structures.

The 3H defect consists of an interstitial carbon atom, while the H3 defect is formed by two next-nearest-neighbor substitutional nitrogen atoms separated by a vacancy. Because the 3H defect requires relatively little energy to relax into a normal diamond bond, it is much less stable than the H3 defect at high temperature. The 3H defect has often been observed in natural diamonds. We detected the 3H defect in 69 of 100 tested natural diamonds (Choi et al., 2009); all 69 also showed a line at 540.7 nm. Interestingly, when the H3 center was present without the 3H center, the 540.7 nm line could not be detected. This suggested there was a relationship between the 3H center and the 540.7 nm defect.

These PL spectra were taken from a diamond before and after irradiation and subsequent annealing at 600°C.



To establish whether the 540.7 nm peak belongs to the 3H center, we measured PL spectra taken with 488 nm laser excitation at liquid helium temperature on five type Ia diamonds that initially did not have the 3H defect, and the spectra were collected again after the stones were irradiated in an electron beam (10 MeV , $5 \times 10^{16} \text{ electrons/cm}^2$) and then after annealing at 600°C . Following are the results:

1. Before irradiation, none of the diamonds had a 3H center and no PL emission was detected at 540.7 nm.
2. After irradiation, 540.7 nm luminescence appeared along with 3H luminescence in all samples.
3. After heating, the 3H defect and 540.7 nm feature disappeared, and there was some loss of GRI luminescence.

On the basis of these observations, we suggest that the emission line at 540.7 nm belongs to the 3H center and an interstitial carbon atom.

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OPTICAL PROPERTIES OF SILICON-RELATED DEFECTS IN CVD SYNTHETIC DIAMOND

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The presence of silicon in diamond is routinely established by detecting the 737 nm zero-phonon line (ZPL) using photoluminescence or optical absorption spectroscopy. The 737 nm ZPL is attributed to the negatively charged Si split-vacancy center (Si-V^-). Unless preventive measures are taken, Si impurities may be introduced into chemical vapor deposition (CVD)–grown synthetic diamond by etching of the Si-containing reactor components. Intentional Si-doping has been achieved for both CVD and high-pressure, high-temperature (HPHT) synthetics. The occurrence of (Si-V^-) in natural diamond is rare, with only about 10 gem-quality examples reported thus far. Consequently, observation of (Si-V^-) frequently helps distinguish between natural, CVD synthetic, and treated diamond.

However, the (Si-V^-) signal can be diminished by exposure to UV radiation. Thus, the absence of the 737 nm ZPL does not necessarily rule out Si-related impurities in diamond, which emphasizes the importance of determining optical analogs of other Si-related defects to detect the presence of silicon. Electron

paramagnetic resonance (EPR) and computational studies have shown the existence of the neutral charge state of the Si split-vacancy center (Si-V)⁰, though past studies have not conclusively ascribed a ZPL to it.

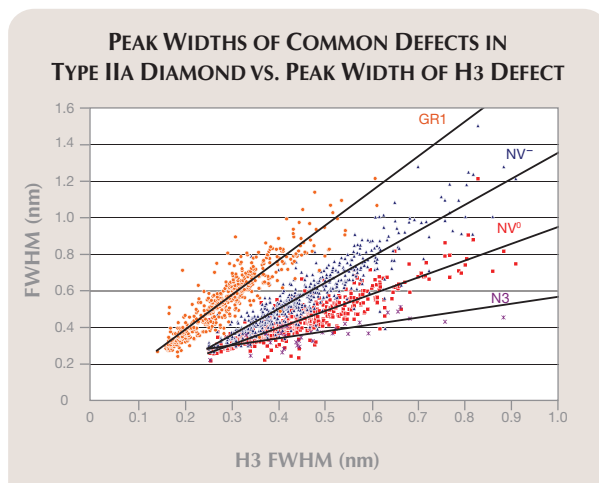
In this study, we characterize and attribute a ZPL at 946 nm, visible in both PL and absorption spectra of some CVD synthetic diamonds, to (Si-V)⁰ by combining the results of optical and EPR measurements. The intensity of the 946 nm feature was found to increase in Si-doped material after successive electron irradiation and annealing treatments, showing similar behavior to the 737 nm line and suggesting the involvement of vacancies. It was associated with Si by its shift to a longer wavelength when the dominant Si isotope was changed from ²⁸Si to ²⁹Si, consistent with a shift of the 737 nm band. Charge transfer was induced between the neutral and negative charge states by illumination or heating in the dark, allowing calibration factors relating the integrated optical absorption coefficient of their respective ZPLs to the defect concentration to be determined at 77 K. With these coefficients, concentrations for both (Si-V)⁻ and (Si-V)⁰ can be calculated using optical absorption techniques that are readily available in industrial laboratories.

OBSERVATION OF STRAIN THROUGH PHOTOLUMINESCENCE PEAKS IN DIAMONDS

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Brown color in type IIa diamonds is believed to be caused by vacancy clusters (Fisher, 2009), and the depth of color corresponds to the degree of strain (Fisher et al., 2006). Since HPHT treatment can remove brown color from type IIa diamonds but results in only a limited reduction of strain, the ability to qualitatively assess the level of strain in diamonds is of important geological significance.

An indirect but relatively consistent indication of strain can be obtained from the peak widths of defects commonly observed in photoluminescence (PL) spectra. We took PL spectra (liquid nitrogen temperature) of 600+ type IIa diamonds and 100 type IIb diamonds. In the type IIa diamonds, the peak widths for the GR1, NV⁰, NV⁻, H3, and N3 defects all showed a linear relationship. When these data were plotted in units of meV, they displayed significant overlap in both position and slope. These defects are known to involve different numbers of nitrogen atoms (none, one, one, two, and three, respectively) and various electronic charges, but all contain a single vacancy. Other known defects, including the H4 (nitrogen B aggregate with a vacancy) and the Si-V also showed a linear relationship. However, the 3H defect (ascribed to the carbon interstitial and not directly related to a vacancy) had peak widths that fluctuated within a narrow range and showed minimal to no correlation with either strain or



Peak widths for over 600 type IIa diamonds were calculated for some of the commonly observed defects in their PL spectra. The width of the H3 defect was chosen as the abscissa due to its near-universal detection in PL spectra. Although the peak widths are more appropriately compared in units of meV, they are shown here in nanometers so the data are better separated and distinguished. The N3 peak was detected with 325 nm laser excitation, the H3 defect with 488 nm excitation, and the NV centers and GR1 defect with 514.5 nm excitation.

the peak widths of the vacancy-related defects.

We also analyzed 20 grayish green natural diamonds. Their PL spectra typically contained peaks at 701, 787, and 794 nm, which are ascribed to a nickel-nitrogen vacancy complex (Tretiakova, 2009). The widths of these PL peaks also showed a linear relationship with the GR1 defect.

Several peaks that are commonly observed in the PL spectra of natural diamonds, but which have unknown configuration, displayed a tendency similar to those of the defects shown in the figure; these include peaks at 505, 612.4, and 776.5 nm. Other peaks of unknown origin, such as those at 535.8 and 648.2 nm, do not show corresponding changes in peak width, which suggests they are not affected by strain. By analogy with the known defects, we postulate that configurations for the defects causing the peaks at 505, 612.4, and 776.5 nm may include a vacancy, while those for the defects with peaks at 535.8 and 648.2 nm do not.

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CHARACTERIZATION OF SOME NATURAL AND TREATED COLORLESS AND COLORED DIAMONDS

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Methods for altering color in diamonds are constantly improving, so determining the origin of a diamond's color poses a tremendous ongoing challenge for gemological laboratories. The origin of color in most natural diamonds can be unambiguously established through absorption and photoluminescence (PL) spectroscopy, and polarized light and fluorescence microscopy.

EGL USA performed comprehensive testing to characterize the origin of color of 50 diamonds, known to be treated or untreated, ranging from colorless to near-colorless, yellowish green, orange, brown, pink, and black. The samples were characterized with a Thermo FTIR spectrometer to specify diamond type, an SAS-2000 for visible-range absorption spectroscopy, and a Horiba Jobin LabRam instrument (514 and 632 nm excitation) for PL spectroscopy. This study confirmed several spectroscopic peculiarities in treated and untreated diamonds.

In the PL spectra of the natural black diamonds, the zero-phonon lines (ZPLs) of vacancy-related optical centers were very broad (e.g., the ZPL of the GR1 center could not be resolved). These same lines were considerably narrower in the artificially irradiated black diamonds.

The PL spectra of almost all the untreated type IIa and IaB diamonds revealed a weak GR1 center with a sharp doublet at 741/744 nm. In contrast, the GR1 center was never observed in the HPHT-treated diamonds, unless it had been reintroduced by subsequent low-dose irradiation.

The PL spectra of many of the untreated type IIa diamonds exhibited at least traces of the ZPL of the 576 nm center, which may overlap with the ZPL of the 575 nm (NV⁰) center. The 576 nm center was rarely observed in the HPHT-treated diamonds.

At liquid-nitrogen temperature, the 637 nm (NV⁻) center of most of the HPHT-treated diamonds had a full width at half maximum (FWHM) greater than 0.6 nm. In the untreated diamonds, this line was usually less than 0.5 nm wide. In the PL spectra of the untreated type IIa diamonds, several weak lines were invariably detected between 550 and 580 nm (e.g., 566, 575, 576, and 578 nm). Within this range, the HPHT-treated type IIa diamonds usually revealed only the ZPL of the 575 nm (NV⁰) center.

PINK HPHT SYNTHETIC DIAMONDS—A NEW COLORATION TECHNIQUE

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New high-pressure, high-temperature (HPHT) growth techniques and post-growth color treatments applied to synthetic diamonds present new identification challenges. Recently observed in the GIA Laboratory were three pink HPHT-grown synthetic diamonds that had been treated by a combination of irradiation and HPHT annealing to achieve their desirable colors. These were grown with controlled amounts of nitrogen, enabling better results with post-growth color treatments.

The three synthetics (0.14, 0.20, and 0.53 ct) were studied using standard gemological testing, infrared spectroscopy, visible spectroscopy, photoluminescence (Raman) analysis, and observation of luminescence with the DiamondView instrument. The three gems were quite clean, with few inclusions and a very even distribution of color. The latter feature is particularly important, as HPHT synthetic diamonds usually have very well-defined growth structure and color zoning. In the strong short-wave UV



These three synthetic diamonds (0.14, 0.20, and 0.53 ct) owe their coloration to a combination of carefully controlled growth and treatment. Subtle growth structures are visible in their corresponding DiamondView images. Photos by Jian Xin (Jae) Liao (top), K. S. Moe (bottom left and right), and P. Johnson (bottom center).

radiation of the DiamondView, however, the samples displayed a subtle growth structure that is characteristic of synthetic diamonds; in some cases, this structure was more obvious in the pavilion facets.

Mid-infrared absorption spectra showed that all three synthetic diamonds had very low concentrations of aggregated nitrogen. It is believed that the aggregated nitrogen content is intentionally controlled during the growth process, enabling nitrogen-vacancy (NV) centers to be induced during post-growth treatment. Absorption features due to these NV centers, evidenced in the visible spectra, are responsible for the desirable purplish pink and pink colors of these synthetic diamonds. They received color grades of Fancy pink, Fancy Intense purplish pink, and Fancy Vivid purplish pink.

CHARACTERIZATION OF DISTINCTIVE COLOR ZONING AND VARIOUS INCLUSIONS IN LOW-GRADE DIAMONDS

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With the exception of colored diamonds, the value of most natural diamonds is directly related to their lack of color, and their clarity. However, bort and other heavily included diamonds typically used for industrial purposes may still present interesting study samples because of their internal features. These inclusions may affect the color of diamonds depending on how they are polished. The environment of diamond crystallization influences the occurrence of such inclusions, which also are manifested in various complex forms by epigenetic causes.

We investigated unusual inclusions in low-grade natural diamond crystals. Each sample was classified by the forms and colors of its inclusions. The chemical composition and structure of each inclusion were analyzed with scanning electron microscopy–energy dispersive spectroscopy, X-ray fluorescence, high-resolution transmission electron microscopy–selected area electron diffraction, and confocal micro-Raman spectroscopy. The growth directions and properties of the inclusions were observed through their cathodoluminescence patterns. We also used normal and focused FTIR spectroscopy to characterize the host diamonds.

Normal FTIR analysis did not reveal a correlation between inclusions and diamond type; most of the diamonds were classified as type IaAB. However, in samples with triangular-shaped color zoning, focused FTIR spectroscopy showed the nitrogen content inside and outside color zones was correlated with diamond type. Analysis of the structures and chemical composition proved that most of the inclusions were oxides of iron with various trace elements. Graphite inclusions are often found in natural diamonds; these inclusions typically appear dark gray and have

dendritic structure, hexagonal form, or fibrous elements. However, in the samples examined in this study, the shape and color of the inclusions varied, and graphite inclusions were not identified in the inclusion analysis using Raman spectroscopy. Our observations demonstrated a correlation between chemical composition and the resultant structure and color of various inclusions present in these low-quality diamonds.

MINERALOGICAL CHARACTERISTICS OF DIAMONDS FROM THE NURBINSKAYA PIPE, YAKUTIAN DIAMOND-BEARING PROVINCE, RUSSIA

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Discovered in 1996 in the eastern part of the Yakutian diamond-bearing province, in the Nakynsky area, the Nurbinskaya kimberlite pipe has a high diamond content. This study was conducted to identify the diamonds' typomorphic features. More than 6,000 samples from the current production were grouped into the varieties classified by Orlov (1977) according to crystal morphology, internal structure, physical properties, and impurities. The following percentages for different size classes were tabulated:

Variety I:	75.0–81.9%
Variety III:	0–1.3%
Variety IV:	8.5–12.1%
Variety V:	0.8–3.9%
Varieties VIII–IX:	6.3–11.6%

Although variety I prevailed in this pipe, its percentage was lower than that recorded for other Yakutian deposits. Most variety I diamonds had flat faces that were stepped and polycentric. Crystals with rounded faces were less common. The variety I diamonds were mainly light yellow, with some dark browns among the smaller crystals. When exposed to UV radiation, they displayed a noticeable blue and violet fluorescence in different crystals.

Variety IV diamonds from this pipe contained two subgroups of crystals: (1) samples with a thin or barely noticeable fibrous coating, and (2) samples with a thick or very thick fibrous coating. In some samples, the surface was not fully coated. We have not found such crystals in other Russian diamond deposits. Samples with a thick coating had a fibrous component that significantly dominated over the core. As many as three color zones could be seen on broken areas of the thickly coated crystals. Polycrystalline aggregates of variety VIII occasionally had coatings. Variety V was represented mainly by crystals of complex shape with octahedral faces and rounded dodecahedral surfaces.

The most common inclusions were those of ultramafic paragenesis: olivine and sulfides. Chromite, purple Cr-bearing pyrope,

and diamond inclusions were observed less frequently.

IR spectroscopy revealed the presence of A, B1, B2, and H defects in the diamonds. The A defect featured a complex distribution (with two maxima, 5–20 and 30–40 cm^{-1}) that appears to be characteristic of this material. Other defects were consistent with those in other diamonds, and Raman spectroscopy did not reveal any peculiarities.

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THE NATURE OF BLACK COLORATION IN GEM-QUALITY DIAMONDS FROM BRAZIL

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This study investigated the black coloration in diamonds from alluvial placers of the Macaubas River basin in Minas Gerais, Brazil. The samples consisted of three rounded octahedrons and two tabular dodecahedrons, with an adamantine luster. From each of these crystals, a 0.5-mm-thick plate was sawn. The octahedrons were sawed then polished, while the dodecahedrons were only strongly polished. The plates showed uniform, very saturated brown (dodecahedrons) or green (octahedrons) coloration, and they contained no color-causing inclusions. However, we did not know whether the brown samples were naturally colored or if they turned brown as a result of heating during polishing of the plates.

In all crystals before polishing, visible-range absorption spec-

tra (at room temperature) showed transmission starting at 700 nm, with a GR1 line at 740 nm and a band at 1076 nm. The infrared spectra of all crystals showed the nitrogen absorption systems A, B1, and B2, and a band with a maximum at 1530 cm^{-1} (absorption coefficient 0.6–0.7 cm^{-1}). This band is due to irradiation and proves there was no subsequent heating to temperatures above 200°C. In the polished plates, the GR1 system was detected in the absorption spectra of all samples. The H3 system was only detected in the absorption spectra of the brown plates. The spectra of all the plates also featured a system with the main band at 1078 nm (absorption coefficient 0.8 cm^{-1}).

The plates had a heterogeneous distribution of the main nitrogen defects A and B1, with some weak color variations in one green plate. Annealing of all plates was performed for 5 minutes at temperatures up to 600°C at 50° intervals and FTIR and visible-range spectra were recorded at each interval. Thermal behavior of the 1450 cm^{-1} band showed that the brown samples had been heated during polishing to temperatures above 600°C, while the green samples were heated during polishing to temperatures of 400–500°C. After annealing at 600°C, the green plates became greenish brown, and the GR1 band was reduced in intensity by 50%.

Testing of these plates revealed that all of the “black” diamond crystals were originally dark green, and that plates sliced from two of them turned brown because of heating during the polishing process.

This study was supported by the Russian Federal Purpose Program “Scientific and scientific-educational cadres of innovative Russia” for 2009–2013.

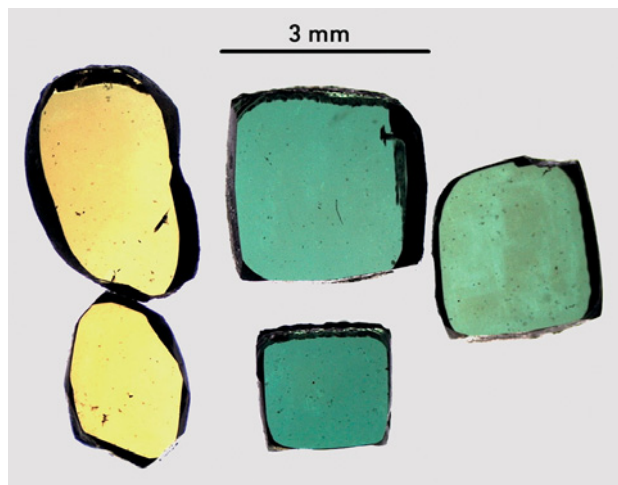
DONOR NITROGEN AGGREGATION IN SYNTHETIC DIAMONDS ANNEALED IN THE GRAPHITE STABILITY FIELD

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This study focused on the C→A nitrogen aggregation that occurs during high-temperature annealing of high-pressure, high-temperature (HPHT) synthetic type Ib diamonds grown in nickel- and cobalt-containing systems. In the first series of experiments, the synthetic diamonds were subjected to high-temperature treatment in the presence of argon gas under atmospheric pressure. The samples were annealed at increasing temperatures (from 1400 to 1700°C) at 50°C intervals. At an annealing temperature of 1700°C, the nickel-containing diamonds showed an absorption increase at 1282 cm^{-1} due to A centers and a simultaneous decrease in absorption at 1344 cm^{-1} associated with C cen-

These 0.5-mm-thick plates were cut from “black” diamonds and studied for this report. Photo by E. Vasilyev.



ters. The cobalt-containing samples revealed no aggregation even at higher temperatures (1800°C).

The activation energy of aggregation (E_A) was 6.6 ± 0.6 eV in the nickel-containing samples. After the synthetic diamonds had been electron irradiated ($3 \text{ MeV per } 2 \times 10^{18} \text{ cm}^{-2}$) and annealed at 900°C for 120 minutes, however, nitrogen aggregation was observed at 1400°C. This was due to the formation of NV^- and N_1 radiation-induced defects. The E_A value decreased to 0.5–1.5 eV in the nickel-containing samples, and to ~ 2.9 eV in the cobalt-containing synthetics.

The lower activation energy (and, in turn, the higher aggregation rate) can be attributed to two additional mechanisms involved in the aggregation process:

1. A vacancy mechanism (according to Collins, 1980): $\text{N}_S + \text{N}_V \rightarrow \text{N}_S - \text{N}_S (\text{A}) + \text{V}$
2. A donor-interstitial mechanism: $\text{N}_S + \text{N}_I \rightarrow \text{N}_S \text{N}_I \rightarrow \text{A} + \text{C}_I$

The C→A nitrogen aggregation caused a change in color (from brownish yellow to greenish yellow) and diamond type (from Ib to IaA).

In the second series of experiments, the samples were subjected to low-pressure, high-temperature (LPHT) treatment. They were treated in hydrogen plasma at 1600 and 1700°C. No C→A nitrogen aggregation was observed, and the samples remained type Ib. The IR absorption intensity at 1130 cm^{-1} decreased by 5–10%, and the μ_{1130}/μ_{1344} ratio increased by 8–12%. These effects could be due to proton thermal diffusion from the hydrogen plasma. The protons are localized at diamond structural defects, with some donor electrons from C centers being compensated. As a result, the samples became more colorless. The protons block the C→A aggregation, creating additional crystallographic strain that is reflected in a higher μ_{1130}/μ_{1344} ratio.

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NEW ULTRA-DEEP DIAMOND CLEANING TECHNOLOGY

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Clarity is one of the most important characteristics in determining the value of natural diamonds. Yet the efficiency of existing technologies for surface and fracture cleaning leaves much to be desired. The reagents in these technologies can only be used between 220 and 240°C, under a pressure no greater than 40 atm. And even if the process is repeated several times, the diamonds are not completely clean.

A new ultra-deep diamond cleaning technology is now available that surpasses existing methods in quality and speed. The innovative aspect of this technology is its capacity for temperatures above 300°C and acid vapor pressures of 200–400 atm. Under such conditions, the reagent activity is so high that only one mixture of reagents (rather than two or three) is needed. Cleaning becomes a faster, more efficient one-step process. Even large contaminant inclusions that reach the surface through tiny fractures are cleaned out completely. The new ultra-deep cleaning technology is not a natural diamond enhancement technology because the diamond is neither changed at the atomic level as during color enhancement nor laser-drilled and fracture-filled as during clarity enhancement. The diamond is simply cleaned from surface contaminants and inclusions. This technology increases the value of the diamond 30–100% and can be used by large diamond mining and selling companies.

GEM LOCALITIES AND FORMATION

BLUE AND PINK SAPPHIRES FROM MULING, NORTHEASTERN CHINA

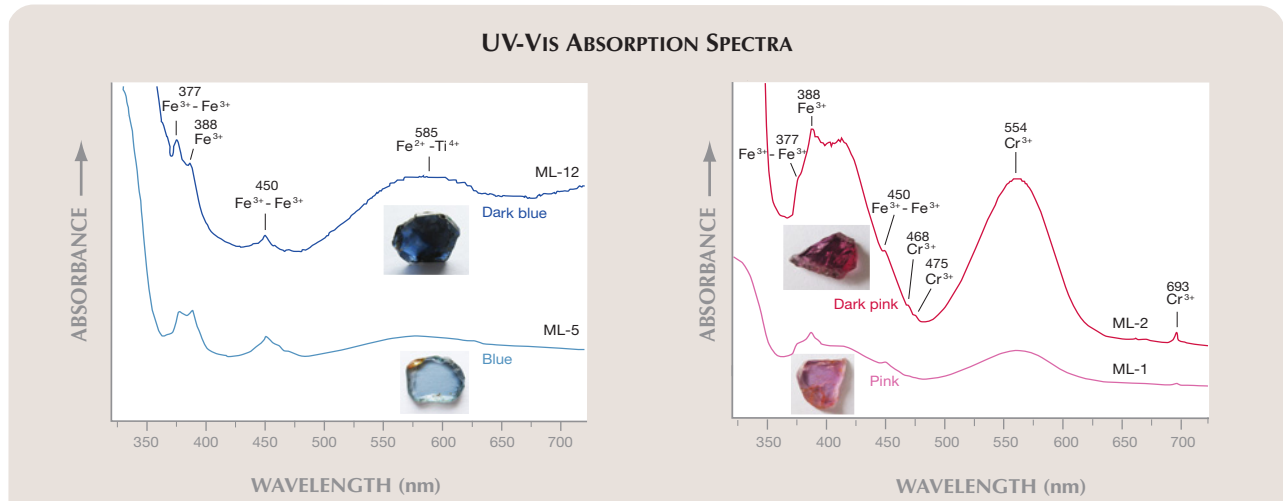
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Pink and blue sapphires occur in alluvium derived from Tertiary alkali basalts at Muling, in the northeastern Chinese province of Heilongjiang. Associated heavy minerals in the alluvium include zircon (Chen et al., 2011), garnet, spinel, enstatite, and olivine; some are gem quality. The Muling deposits were discovered in 1985, but exploitation for gem production is still limited.

Twenty-five blue and pink sapphires from Muling were characterized using standard gemological methods including infrared and UV-Vis spectroscopy. The samples consisted of 13 polished blue sapphire plates (0.10–1.14 g), five polished pink sapphire plates (0.16–0.51 g), and seven rough blue and pink sapphires (1.12–10.36 g). The rough blue sapphires mostly formed six-sided barrel-shapes. SG values were 3.98–4.09 (rough), 3.94–4.08 (blue plates), and 4.02–4.05 (pink plates). RIs were $n_o = 1.768$ – 1.770 and $n_e = 1.760$ – 1.762 , with a birefringence of 0.008–0.009. The blue sapphires were inert to both long- and short-wave UV radiation, while the pinks showed moderate to faint red in long-wave and were inert to short-wave UV. The sapphires' internal features consisted of two-phase, fluid, and various crystal inclusions (colorless zircon, apatite, and short rutile needles), as well as hexagonal color zones.



UV-Vis spectra of sapphires from Muling show absorption features related to Fe and Ti (blue samples, left), or Cr and Fe (pink samples, right).



This map shows the major rock types and associated mineral localities in southern Brazil.

No absorption bands resulting from O-H (at $\sim 3400\text{--}3200\text{ cm}^{-1}$) were visible in the pink samples; three blue samples showed small absorptions at 3307 and 3231 cm^{-1} . UV-Vis spectra of the pink sapphires showed Cr^{3+} features (i.e., two large absorption bands centered at ~ 400 and 550 nm). A diagnostic narrow band at 693 nm was also attributed to Cr^{3+} . Small bands at 388 nm (attributed to Fe^{3+}) and at 377 and 450 nm (attributed to $\text{Fe}^{3+}\text{-Fe}^{3+}$ pairs) also were observed in the pink sapphires. The blue sapphires had narrow peaks at 377 , 388 , and 450 nm that were weaker than the $\text{Fe}^{2+}\text{-Ti}^{4+}$ absorption band at 585 nm .

Although these sapphires have yet to be mined commercially, the Muling deposit is a promising source of gem corundum.

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GEM MATERIALS IN THE SOUTH OF BRAZIL

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The southern Brazilian states of Paraná, Santa Catarina, and Rio Grande do Sul contain various gem deposits in several geologic units.

These minerals are used as faceted gems for the jewelry trade, and also as ornamental and collector stones.

Most important are the huge agate and amethyst geode deposits in Paraná Basin, hosted by volcanic rocks of the Serra Geral Formation. The Salto do Jacuí region of Rio Grande do Sul is the main producer of agate, which occurs in a variety of colors and exotic patterns. The region also contains deposits of onyx and carnelian, as well as gem-quality opal. The opal exhibits a range of crystallinity (opal-C and opal-CT) but no play-of-color. It is typically translucent to transparent and can exhibit various attractive bodycolors, including yellow, blue, and red (fire opal).

The main amethyst producer is the Ametista do Sul region of Rio Grande do Sul, where rock crystal, rose quartz, jasper, calcite, gypsum (selenite), and barite can occur in association. Important amethyst deposits are found also in western Santa Catarina and southwestern Paraná States. Natural citrine has not been recovered from these deposits, but significant amounts of amethyst are heat treated to produce this quartz variety.

A number of zeolites, associated with apophyllite, have yielded superb mineral aggregates in geode deposits in Rio Grande do Sul and Santa Catarina States. In northern Santa Catarina, ruby and sapphire (pink, colorless, brown, gray, and black) are found in large colluvial deposits, associated with granulitic rocks. Most of the rough material is opaque to translucent, but it may exhibit special features such as color zoning, chatoyancy, and asterism. Alluvial deposits in the Tibagi River valley of Paraná are known for small but high-quality diamonds. Blue and green sapphire, agate, jasper, rock crystal quartz, and black tourmaline may occur together in the gravel. Rio Grande do Sul contains serpentinite deposits that originated from Precambrian gabbros and peridotites. These specimens are light yellowish green to dark green, with patches, veins, and bands. In the central region of the state, a large deposit of petrified wood is hosted by Gondwana-associated sedimentary rocks. Considered one of the most important earth-silicified fossil wood records, it has become a conservation site where commercial mining is prohibited.

RUBY FROM LIBERIA

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One of these authors recently found rubies and smaller amounts of sapphires while prospecting for alluvial diamonds in two areas of Liberia (Douman, 2011). The sediments consisted of quartz grains and smaller black grains, some of which could be identified as tourmaline and staurolite. One prospecting area lies on the Mano River (along the border with Sierra Leone), while the other



These rubies (and two sapphires) were found in Liberia. The larger crystals with well-defined shapes come from Nimba Province close to the border with Guinea, while most of the smaller waterworn rubies are from the Mano River along the border with Sierra Leone. The smaller of the two sapphire crystals weighs 1.52 g and is 11.6 mm long. Photo by L. Kiefert.

is located in Nimba Province close to the Guinean border. At the latter locality, yellow to green chrysoberyl and orange spessartine also were found.

The Mano River rubies consisted of small waterworn pebbles weighing less than 0.2 g, while those from Nimba Province constituted well-formed crystals larger than 1 g with prism, basal, and rhombohedral faces.

The rubies ranged from near-opaque and purplish red for the larger crystals to transparent and pinkish red to red for the smaller ones. The larger purplish red crystals were heavily twinned in three directions following the rhombohedral faces. The smaller crystals from the Mano River were not quite as heavily twinned, but showed iron oxide staining in the fissures more frequently than the larger crystals. In addition, networks of partially healed fissures were observed in some samples from the Mano River. Initial microscopic examination of samples from both deposits showed inclusions of black rounded and elongated crystals, as well as clusters of small rounded transparent crystals (most likely zircon). One well-formed zircon crystal was identified by Raman spectroscopy in one of the samples from Nimba Province.

The twinning pattern and chemical data for the Liberian samples from both localities fit well with other African rubies such as those from Malawi, Tanzania, and Mozambique, while they were distinctly different from Burmese, Nepalese, Tajik, Afghan, Sri Lankan, and Vietnamese rubies. Cr contents from both localities varied between 0.3 and 0.7 wt.%, while Fe values ranged from approximately 0.6 to 1.2 wt.%.

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SYSTEMATIC DIAMOND DESCRIPTIONS FOR USE IN GEOLOGY AND EXPLORATION

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Diamond crystal descriptions are used by dealers, cutters, physicists, and geologists. Yet each discipline has different needs and applications, and no coherent classification scheme exists. Researchers such as Orlov, Harris, Gurney, Robinson, Afanasiev, and Spetsius have published valuable works that describe diamond crystals, but objective comparison between terminologies is often elusive. For the purpose of geologic study, exploration, and resource evaluation, an industry-wide classification scheme is proposed.

As one of the few commercial diamond recovery laboratories in the world, the Saskatchewan Research Council Geoanalytical Laboratories Diamond Services (SRC-GLDS) has worked with various sectors of the industry. SRC-GLDS has implemented the proposed scheme into its diamond analysis and received substantial positive feedback. A trained geologist, gemologist, or mineralogist can use this system to generate a complete description of diamond crystals, thereby producing consistent and objective raw data.

The diamond classification scheme calls for observation and qualitative determination of the following criteria: color, clarity, inclusions, crystal shape, surface features, and descriptors. Color is broken down into seven groups based on saturation. Clarity is represented by three degrees of light transmission. Inclusions are divided into five categories, ranging from absent to heavily included. Diamond morphology has been narrowed down to eight primary and secondary crystal shapes for easy reference. Resorption of the octahedron is compared to the visual standards devised by Robinson (1979). Surface characteristics that affect the stone's overall appearance are placed into nine categories. Last, six descriptors are provided for other common features, such as twinning and breakage.

This systematic diamond crystal description scheme is supported by qualitative standards referenced through the use of photographs and charts; it also incorporates detailed discussion to aid classification. Analysis of the data produced can be used to aid geologic study and resource evaluation of diamond deposits. SRC-GLDS's goal is to create international consensus for this classification scheme within an enigmatic industry.

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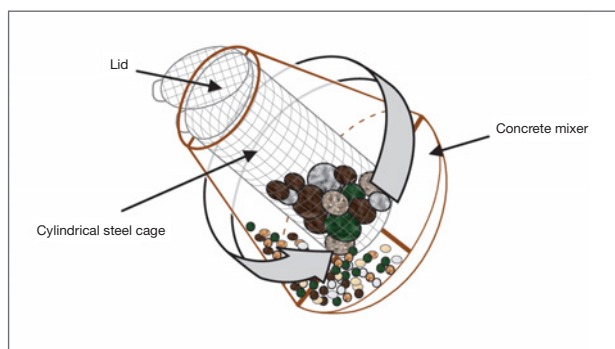
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USING A CONCRETE MIXER TO SORT GEM-BEARING GRAVELS FOR ARTISANAL AND SMALL-SCALE MINING

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An inexpensive concrete mixer can easily be converted into a washing and sorting machine for gem-bearing gravels. The inside of the mixer is fitted with a cylindrical steel cage (40 cm in diameter and 80 cm long) that functions as a trommel. The cage can have a mesh size of 1 inch (2.5 cm) or any other desired size. This changeable steel cage is installed inside the concrete mixer body by connecting it with bolts to the base and side walls. Around the curved area toward the bottom of the mixer, openings of suitable size are cut and covered with sieves that are bolted to the surface. Therefore, sieves of various sizes can be changed quickly as needed.

To operate the machine, the trommel is filled with gem-bearing gravels and the mixer is spun at an angle of ~20–45°. The angle and



This diagram shows a concrete mixer fitted with a cylindrical steel cage that functions as a trommel.

rotational speed are adjusted for maximum efficiency. A small water pump sends high-pressure spray through a ½ inch nozzle into the rotating trommel. After a few minutes, once the water flowing out of the mixer is clean, the washing and sorting is complete. The coarse-grained materials are trapped inside the trommel, while the medium-grained pebbles and gravels are left in the bottom of the mixer. The fine-grained sand, silt, and clay are eliminated with the washing slurry through sieves. The coarse and medium-sized material can then be easily collected and processed by hand-picking.

The thick body of the mixer is sturdy enough to handle the hard work of sizing stream sediments, and the machine can be conveniently moved between various mining sites. With this device, artisanal and small-scale miners can bring more product to market.

PETROGENESIS OF THE LI-BEARING STEWART PEGMATITE, PALA, CALIFORNIA

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A study is underway to unravel the petrogenesis of the gem- and lithium-bearing Stewart pegmatite in Pala, California, which is a source of pink tourmaline and other gems. Prevailing concerns include: (1) the relationship between the host gabbro and the pegmatite, (2) the age of the gabbro and the pegmatite, (3) the source and nature of the pegmatite-forming material, (4) the temperature and pressure of pegmatite crystallization, and (5) the duration of pegmatite formation.

The host gabbro and the Stewart pegmatite have initial ⁸⁷Sr/⁸⁶Sr ratios of 0.7037 and 0.7040, respectively, consistent with a common origin. The Sycamore Flats olivine gabbro, a small-scale analog of the Pala gabbro, contains 48% SiO₂ and minor micropegmatitic stringers in its center with 77% SiO₂. The micropegmatites' setting indicates they were derived from the gabbro magma as immiscible components. Findings show that the micropegmatites formed from a gaseous fluid, not a silicate melt.

We interpret that the Stewart pegmatite was derived from an immiscible gaseous fluid derived from the crystallizing gabbro. The U/Pb age of zircon from the Pala gabbro is 103 Ma, while the ⁴⁰Ar/³⁹Ar age of Stewart muscovite is 100 Ma; adjusting for the temperature of Ar retention in muscovite, the gabbro and pegmatite are the same age.

After pegmatite emplacement, volatiles rose within the pegmatite, making the footwall cooler than the solidus and forming the aplitic-textured footwall. After most of the pegmatite had crystallized, pegmatite formation continued as gaseous fluids moved up from the core zone, autometasomatically replacing the earlier-formed pegmatite. The metasomatic pegmatite formed upward-tapering "chimneys." The outer portions of the chimneys consist of albite, quartz, muscovite, and perthite, while their cores are largely albite-containing, gem-bearing miarolitic cavities.

Tourmaline in the chimneys systematically crystallized as schorl in the uppermost part of the chimney, followed by green/blue elbaite in upper miarolitic cavities, pink elbaite and morganite in intermediate cavities, and finally pink elbaite and kunzite in the lowest cavities. The Li-rich core zone, which is devoid of miarolitic cavities, consists of albite, petalite, heulandite, lepidolite, frozen elbaite, amblygonite, and frozen laths composed of petalite, spodumene, heulandite, stilbite, and tridymite.

A STUDY OF RUBY ON PAINITE FROM THE MOGOK STONE TRACT

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Rubies from the Mogok Stone Tract in Myanmar are among the finest on Earth. Although the marble source in the Mogok metamorphic belt is well established, the process of ruby formation has been a subject of much debate. Iyer (1953) attributed this process, and that of spinel, to metamorphism of the aluminous component in the carbonate sediment. Gübelin (1965) proposed a pneumatolytic interaction of granitic liquids with the marble. Garnier (2003) and Giuliani et al. (2007) hypothesized that ultra-saline hydrous fluids from evaporitic components of the sediments scavenged the silica to leave corundum through a metasomatic reaction. On the basis of mineral associations (scapolite, cancrinite-group, moonstone, etc.) in some ruby specimens, Harlow (2001) argued that they formed similarly to a skarn.

Our observations of ruby overgrowths on painite, CaZrAl₉O₁₈, have defined the mineral assemblages and relative timing of crystallization in the Mogok Stone Tract. At Wetloo, an abundance of painite was found at the contact of a pegmatite with marble. Two painite specimens with overgrowths of ruby were sectioned to permit textural and mineral examination with X-ray diffraction, electron microprobe, backscattered-electron imaging, and microscopic study. The painite crystals are actually clusters of parallel hexagonal prisms (rods), with an interstitial mixture of zircon + ruby and foitite + zircon. Coronal overgrowths on painite and vermicular intergrowths indicate a second generation of foitite, plus new margarite, zircon, and srilankite. Corundum is in intimate contact with foitite and some zircon.

We propose that painite formed from a skarn reaction of a Zr-rich pegmatitic fluid with marble. A subsequent fluid led to a reaction of painite to zircon ± foitite ± margarite ± srilankite, though perhaps not in a single stage, as evidenced by the differences in silica activity observed in the concurrent phases. The intergrowths and overgrowths of corundum suggest a coeval to late fluid-carbonate reaction; alumina and Cr are at least partially sourced from painite. Clearly, both textures and phase assemblages indicate reaction relationships for the formation of corundum with painite. U-Pb dating of Wetloo zircon yielded 16 ± 0.5 Ma (Thu, 2007), indicating they are younger than the 18.7–17.1 Ma (both ± 0.2 Ma) age of other Mogok ruby associations reported by Garnier et al. (2006). For Mogok ruby, multiple ages and mechanisms of formation must be considered.

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GEMSTONES FROM MEXICO—A REVIEW

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Nature endowed Mexico with enormous metallic and nonmetallic mineral resources. But despite extensive research, scientists still have not properly explored the Mexican territory from a mineralogic or especially a gemological point of view (Victoria, 1998; Ostrooumov, 2001). Moreover, some gemologists have considered it an insignificant source of gem materials. Unfortunately, there have been relatively few publications dedicated to the evaluation and characterization of Mexican gem deposits, while those reports that have been published are often confusing and even contradictory.

The most economically important gems produced in Mexico today are volcanic opals, with or without play-of-color, from the states of Jalisco and Querétaro. The color and crystal chemistry of these volcanic opals were investigated recently (Ostrooumov, 2007a,b). Other traditional gems and collector's stones—such as moonstone, topaz, danburite, amethyst, fire agate, amber, turquoise, malachite, obsidian, “onyx” marble, pearl, and coral—are exploited on a limited scale. Tourmaline, sphene, peridot, and grossular and almandine are rare. Recently, the first Mexican amazonite was discovered in Chihuahua State, and the first jadeite-bearing pebbles were found in secondary deposits in the Vizcaíno Peninsula of Baja California Sur. These finds demonstrate the importance of systematic research of the Mexican subsoil, which could lead to the discovery of other gem localities.

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THE PEDERNEIRA PEGMATITE, MINAS GERAIS, BRAZIL: GEOLOGY AND GEM TOURMALINE

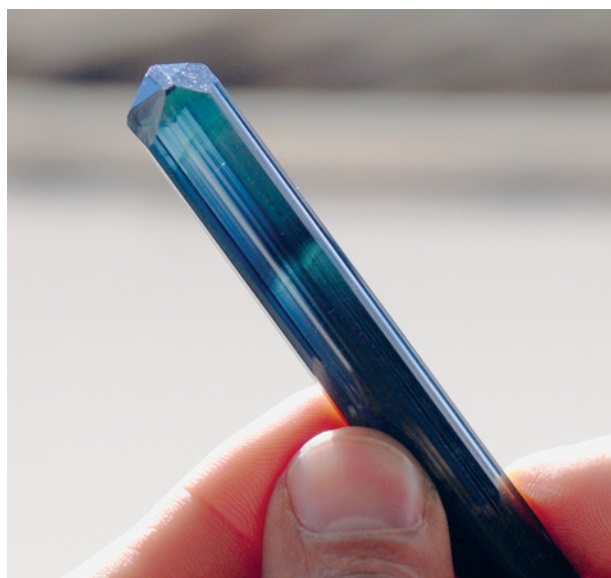
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The Pederneira mine, located a few kilometers north of the famous Cruzeiro mine in the São José de Safira area of Minas Gerais, Brazil, produced an extraordinary quantity of gem tourmaline crystals from 1980 to 2006. In 2010, U.S.-based Fine Minerals International began a geologic prospecting and under-

This gem-quality tourmaline crystal was recently produced from the Pederneira mine in Minas Gerais, Brazil. Photo by Marco Lorenzoni.



ground mining project to evaluate the deposit's remaining potential. The lead author has been involved in the geologic study of Pederneira and collected new data and representative samples of pegmatitic rocks, minerals in pockets, and tourmaline gem material. A complete gemological characterization of tourmaline from this locality was conducted in collaboration with the University of Milan and the National Council of Research in Milan.

The Pederneira tourmaline deposit is characterized by two major pegmatitic bodies: a lower one miners call *Dilo*, and an upper one known as *Dada*. These two masses are roughly prismatic in shape and dip steeply to the southwest. They are interconnected, and bounded at the top and bottom by subhorizontal barren pegmatitic dikes. The host rock is composed of biotite- and muscovite-bearing paragneiss, with quartz and plagioclase, and accessory garnet and tourmaline (dravite). Both pegmatites exceed 30 m in width. The Dilo pegmatite contains large enclaves of host rock. Large, spectacular gem-bearing pockets are distributed along the core zone of both the Dilo and Dada pegmatites.

Pederneira's gem tourmaline is characterized by a wide variety of red-to-purple and green colors. Bicolored and "watermelon" crystals are common. Blue-green to grayish blue and blue colors are rarer, as is cat's-eye material (red or green). The high-quality gem crystals in the pockets largely consist of second-generation "pencils" that grew into the cavity in the crystallographic direction of the analogous pole (mostly pedial terminations) or the antilogous pole (mostly pyramidal terminations). Microprobe analyses of the gem material revealed compositions in the elbaite field, with variable contents of fluorine and a high rossmanite component in some pink samples. Foitite was confined to dark green to black portions of the crystals. The only significant minor elements were iron and manganese. At present, the potential for future production is uncertain, and a significant investment in the mining of new exploration tunnels is in progress.

BLUE "OPAL" (OR CRISTOBALITE?) FROM RIO GRANDE DO SUL, BRAZIL

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Rio Grande do Sul is well known for its huge agate and amethyst geode deposits in volcanic rocks. Various colors of opal are also associated with these deposits, especially in areas near the main agate production center of Salto do Jacuí. The opal is usually found within geodes in alternating layers with chalcedony, cementing breccias, or irregularly deposited along fractures and ancient lava flow structures. The degree of crystallinity varies considerably,

from highly disordered opal-CT to well-ordered opal-C.

This work focused on some blue "opals" that occur in the region. They have greater refractive index (1.475) and specific gravity (2.25) values than those reported for pure Brazilian opal and other opal occurrences worldwide. Their X-ray diffraction pattern presents all the characteristics of a pure cristobalite spectrum, with a very intense and narrow peak at 4.04 Å with a full width at half maximum (FWHM) of only 0.036 Å. The Raman spectrum also shows the typical features of pure cristobalite, with peaks at 419, 232, and 114 cm⁻¹. The main Raman peak has a FWHM as low as 23 cm⁻¹. Furthermore, thermogravimetric studies revealed a transition from α - to β -cristobalite at 266°C. This transition was confirmed by recording X-ray spectra while slowly heating the material from room temperature to 300 °C. The final result of heating true opal should always be α -cristobalite.

We therefore consider this gem material cristobalite. Thermogravimetric analysis can be used as an additional tool to distinguish it from opal-C samples with very high RIs and SGs. Although the material's values still lie below those listed for cristobalite, lower values are to be expected for a porous aggregate that contains water and/or air in its voids. Indeed, this cristobalite contains nearly 2% water that is released from the pores at very low temperatures (39°C), causing it to destabilize and whiten if exposed to heat or dry air for extended durations. We also had the opportunity to analyze a very similar blue "opal" from Oregon. Our results suggest it is identical to the cristobalite material described in this work.

RECENT TRENDS IN WORLD COLORED GEM PRODUCTION

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The U.S. Geological Survey publishes world production figures for more than 80 mineral commodities annually. Colored stone production, unlike that of diamond, is inherently difficult to estimate because of the fragmentary and commonly informal nature of the industry, the lack of government oversight in many of the source countries, and the wide quality variations for each gem material. For these reasons, world production figures for colored stones were not published by the USGS until 2008. Concerns over the misuse of diamonds and possibly other gems to fund civil wars and terrorism have led the USGS to reexamine colored stone production in detail. Based on government data, company reports, and a review of the colored stone mining literature, the agency has estimated global production of amethyst, emerald, ruby, sapphire, and tanzanite for the years 1995 to 2008, and for alexandrite from 2001 to 2008.

From 1995 to 2005, Colombia was the world's leading emerald supplier, accounting for about half of global production by volume.

TABLE 1. World emerald production (1996–2008).^a

Country	1996	1999	2002	2005	2008
Brazil ^b	1,300	460	700	1,500	2,500
Colombia ^b	2,300	2,100	1,800	1,700	570
Russia	—	—	800	618	270
Zambia	570 ^b	445	1,860	1,100 ^b	1,800
Zimbabwe	108	21	33	20 ^b	—
Other ^b	25	29	118	135	111
Total ^b	4,300	3,100	5,300	5,100	5,300

^a Values in kg. Sources: U.S. Geological Survey Minerals Yearbook, company reports, and unpublished data.

^b Estimated; data are rounded to no more than three significant digits.

By 2008, Colombia ranked third in volume, behind Brazil and Zambia. Russia resumed emerald mining in 2001 with the reopening of the Malysheva mine, which shut down again in 2008.

Ruby production in Madagascar and Myanmar appears to have declined in recent years. Tanzania's output likely rose in 2008 with the discovery of the Winza deposits. Ruby mining also seems to have increased in Pakistan and Tajikistan, and to have resumed in Malawi. Greenland and Mozambique, meanwhile, have emerged as new ruby sources.

World sapphire production likely declined in recent years, with diminished output from Afghanistan, Australia, China, Madagascar, Myanmar, Nepal, and Sri Lanka. In Australia, large-scale mining operations either shut down or scaled back because of high production costs. Madagascar's output declined with the depletion of near-surface deposits at Ilakaka and Sakaraha, as well as the 2008–2009 ban on rough gem exports.

Bolivia, Brazil, Uruguay, and Zambia appear to be the world's leading amethyst producers. Uruguayan production has increased in recent years. In Zambia, output from the Kariba mine peaked in 2007.

India's alexandrite production climbed in 2008 after the Vishakhapatnam mines reopened. Russian alexandrite enjoyed a resurgence from 2001 to 2008, with the reopening of the Malysheva mine.

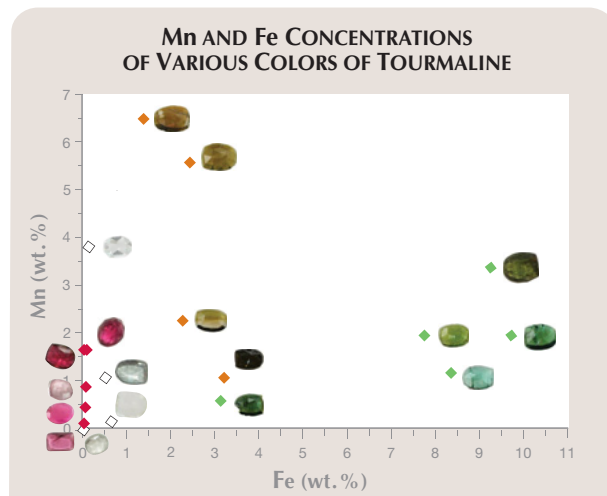
COLORED STONE AND PEARL IDENTIFICATION

SPECTRAL CORRELATION OF MANGANESE AND IRON IN TOURMALINES FROM MADAGASCAR

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Eighteen colored tourmalines (colorless, pink to yellow, green to blue, and brown) from Madagascar were studied using UV-Vis, FTIR, and wavelength-dispersive X-ray fluorescence spectroscopy. The samples had been irradiated and/or heat-treated. Most had prominent amounts of Mn and/or Fe, which were responsible for the different colors. The green to blue samples contained distinctly higher Fe contents, while the lowest Mn contents were detected in the pink to yellow samples. The brown samples had significant Mn and ~3 wt.% Fe.

UV-Vis spectroscopy of the pink tourmalines showed broad absorptions in the vicinity of 510 and 530 nm due to Mn³⁺, but these bands were absent from the colorless tourmaline. After the pale pink and colorless tourmalines were irradiated with an energy of 10 MeV and a dose of 2 × 10¹⁷ electrons/cm² for one hour, they changed to red and yellow, respectively. Greenish blue tourmalines exhibited absorption maxima in the 710–740 nm region attributed to Fe²⁺ (no Cu²⁺ absorptions were detected). Brown tourmalines showed absorption bands at 410 and 710 nm that resulted from Mn²⁺ and Fe²⁺, respectively. Thus, the brown color was produced by a combination of the two absorption bands.



This plot shows the Mn and Fe contents of tourmalines of various colors.

If Mn occurs as Mn²⁺, the tourmaline will appear very pale pink or colorless because the d⁵ configuration does not have spin-allowed transitions. Therefore, Mn²⁺ is not a significant chromophore in tourmaline. When the pale pink tourmaline was irradiated by electrons, a strong absorption band, apparently due to Mn³⁺, appeared in the vicinity of 510 nm. The d⁴ configuration of Mn³⁺ has been assigned to absorption bands at 390 and 510 nm as 'd-d' transitions of ⁵E → ⁵A₁ and ⁵B₂ → ⁵A₁, respectively (Marly and Sandao, 1988). In the FTIR spectra, a combination of stretching and bending modes of cationic units (MOH, where M may be Al, Mg, Fe, Mn, etc.) was observed in the 4600–4300 cm⁻¹ range (Reddy et al., 2007).

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CHINESE FRESHWATER CULTURED PEARLS WITH EXOTIC METALLIC COLORS

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First seen occasionally in multicolored strands, metallic cultured pearls have steadily become more common over the last five years. Entire strands of these exotic cultured pearls are now readily available in lower grades in 6–12 mm sizes. Exceptionally high-grade goods are more difficult to come by, but they are available through special collaboration with producers.

Exotic-colored metallic cultured pearls initially aroused suspicion that their color and mirror-like surface was the product of human intervention. Upon investigation, this has not been the case. There are only a small number of these cultured pearls available, but they have been selling for the same price as standard-color tissue-nucleated products. They are regarded by processors as a nuisance in strand matching.

Compared to the standard Chinese freshwater cultured pearl colors—white to “ivory,” “peach” to “apricot,” and pink to lavender—the metallic ones are easily recognized on close inspection.

Pink sapphires and diamonds complement the exotic color in this metallic cultured pearl ring by Takayas Mizuno. The cultured pearls in this photo are 8–10 mm. Photo by B. Beavers.



They may glisten on the surface as if coated in “aurora borealis” (a commercial coating intended to mimic the natural phenomenon of colorful lights displayed in the polar sky), or they may have a purely metallic look.

Called *strange-color* by the Chinese, the pink-green-“bronze” color is the rarest of the exotic colors of these metallic cultured pearls. Other unusual colors, such as green, purple, and rarely, blue may be seen. Many of the better baroque cultured pearls have a strong orient that appears to float on the surface. As more of these beautiful cultured pearls are used by designers and consumer awareness grows, producers are sure to hand-select them as premium goods.

NATURAL NON-NACREOUS PEARLS FROM THE GIANT CLAM *TRIDACNA GIGAS*

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Non-nacreous pearls from the giant clam *Tridacna gigas* are an often overlooked curiosity in the mollusk realm. Although these specimens are natural, their typically baroque shape keeps them in the shadows of their more attractive nacreous and non-nacreous counterparts.

Known in folklore as the “giant killer clam,” these mollusks have been documented to measure more than four feet across and weigh more than 200 kg. Inhabiting the Indo-Pacific waters, these living jewels display a variety of colors. In death, they become jewels of a different sort. Demand for the giant clam’s meat and ornamental shell has led to overharvesting, and they are now one of the most endangered clam species. This has prompted conservationists to protect the mollusk through nurseries, aquaculture programs, and import restrictions on giant clam products. Noted guidelines have been formalized by CITES (Convention on International Trade in Endangered Species of wild flora and fauna). These restrictions have also made it more difficult for gemologists to obtain specimens for in-depth documentation. Particularly rare are the large blister and loose pearls produced by some giant clams. Of historical note are the Pearl of Allah, the Pearl of Elias, and the Palawan Princess.

The authors recently examined the 2.27 kg Palawan Princess, as well as more than 40 smaller pearls from *Tridacna gigas* and other species from the same genus. The weights ranged from <1 to 72 ct, and sizes ranged from 5.95–5.97 × 3.04 mm to 26.10 × 22.84 × 16.63 mm. Shapes were variable, from symmetrical to baroque, with some being worked. Colors ranged from white to off-white, some being brownish and yellowish; two were an unusual orange color. Physical, chemical, and optical properties were obtained from standard gemological testing (RI, SG, surface

textures, etc.) and from UV-Vis, Raman, FTIR, and EDXRF spectroscopy. Surface luster was porcelainous, waxy, or matte, and the silky flame-like structure observed was variable (none to quite strong). RI and SG were standard for *Tridacna*. One worked specimen turned out to be crafted from *Tridacna* shell. UV-Vis, Raman, FTIR, and EDXRF spectroscopic features were consistent with the coloration and carbonate material of the non-nacreous pearls tested.

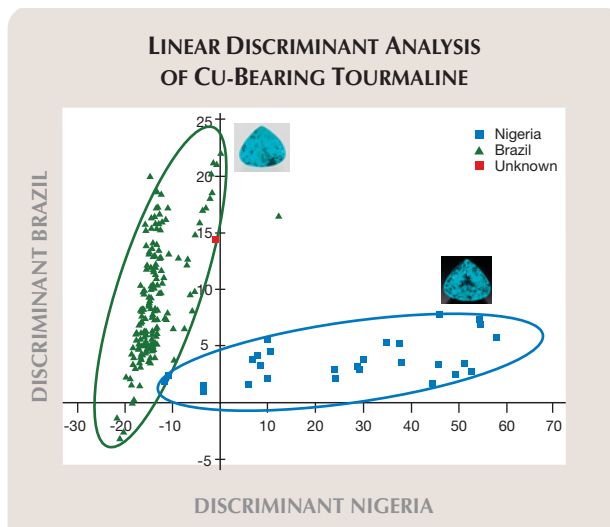
APPLICATION OF DISCRIMINANT ANALYSIS IN GEMOLOGY: COUNTRY-OF-ORIGIN SEPARATION IN COLORED STONES AND DISTINGUISHING HPHT-TREATED DIAMONDS

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Country-of-origin determination for corundum and Cu-bearing tourmaline is a service often sought by the trade. Inclusions and other features are unique to some localities, and microscopy can narrow down the geographic origin considerably. Trace-element chemistry is an integral part of this determination process and becomes critical when samples lack distinctive microscopic features.

LA-ICP-MS analyses of the trace elements in ruby, sapphire, and Cu-bearing tourmaline samples from several deposits were used to measure subtle differences in the geologic environments represented, providing “fingerprints” of the source locality. Linear discriminant analysis is a statistical method related to both multivariate analysis of variance and multiple regression. It considers all elements provided and uses Fisher’s linear model (Fisher, 1936) to place unknown samples into the most likely category of known groups. In addition to selecting the country of origin based on the highest discriminant score, we also superimposed each unknown sample’s scores for the two locations with the highest likelihood of occurrence onto a plot of previous scores for known samples. The plot provides a visual assessment of how closely an unknown sample fits a particular known group relative to another known group. Below is a list of samples and localities analyzed.

- Ruby (522 samples): six elements (Mg, Ti, V, Cr, Fe, and Ga) and nine localities—Mong Hsu and Mogok (Myanmar), Tajikistan, Lake Baringo (Kenya), Songea (Tanzania), Thailand, and undifferentiated deposits in Madagascar, Pakistan, and Vietnam.
- Sapphire (407 samples): six elements (Mg, Ti, V, Cr, Fe, and Ga) and seven localities—Mogok, Kashmir, Andranondambo and Ilakaka (Madagascar), Sri Lanka, Songea (Tanzania), and Lam Dong (Vietnam).
- Cu-bearing tourmaline (336 samples): six elements (V, Cu, Zn, Ga, Sr, and Pb) and three localities—Brazil (including



This plot illustrates how linear discriminant analysis can be used to determine the country of origin for Cu-bearing tourmaline. Here, an unknown sample falls within the discriminant field corresponding to Brazil; it will then be plotted in a diagram comparing Brazil and Mozambique.

Paraíba and Rio Grande del Norte States), Nigeria, and Mozambique.

In addition, we have begun applying the technique to peridot for the purpose of identifying the source of particular gems of archaeological significance.

Discriminant analysis has also been useful in separating HPHT-treated from natural-color diamonds with photoluminescence spectroscopy. Numerous peak heights, full width at half maximum (FWHM) measurements, and peak areas were analyzed. The absorption centers most useful for identifying HPHT-treated diamonds were at 503.2, 575, and 637 nm.

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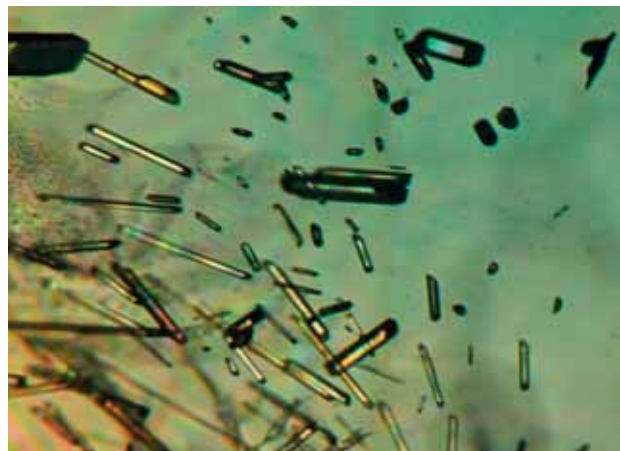
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REMARKABLE GEMS ENCOUNTERED AT THE GEM TESTING LABORATORY, JAIPUR, INDIA

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Since June 2010, several remarkable gems have passed through the Gem Testing Laboratory in Jaipur, India.

Oriented needle-like inclusions were found in a flux-grown synthetic emerald. The needles appeared to be oriented along the prism faces; however, they intersected one another at approximately 60°. This synthetic emerald also contained numerous birefringent and elongated colorless crystals showing a hexagonal pro-



These elongated birefringent colorless crystals with a hexagonal profile were seen in a flux-grown synthetic emerald. Photomicrograph by G. Choudhary; crossed polarizers, magnified 60x.

file. In the absence of flux “fingerprints,” it could easily have been mistaken as natural. The specimen was conclusively identified as synthetic by its infrared spectrum, which did not display any water-related features.

A green quartz contained “lily pad”-like inclusions. The presence of color zones/planes perpendicular to the optic axis indicated synthetic origin, which was confirmed by FTIR analysis.

A dark bluish green serpentine was remarkable for its purple transmission in fiber-optic light. The exact cause of the purple transmission could not be determined, but it appeared to be the presence of minute particles arranged in planes. The specimen also displayed a strong absorption in the yellow-to-green region of the desk-model spectroscope.

Other interesting materials included a synthetic sapphire with natural-appearing milky zones, a fluorite with corundum-like color zones, and glass specimens with transparent included crystals.

Changes in color are produced by heating various colors of natural or synthetic quartz, as shown here for natural samples.

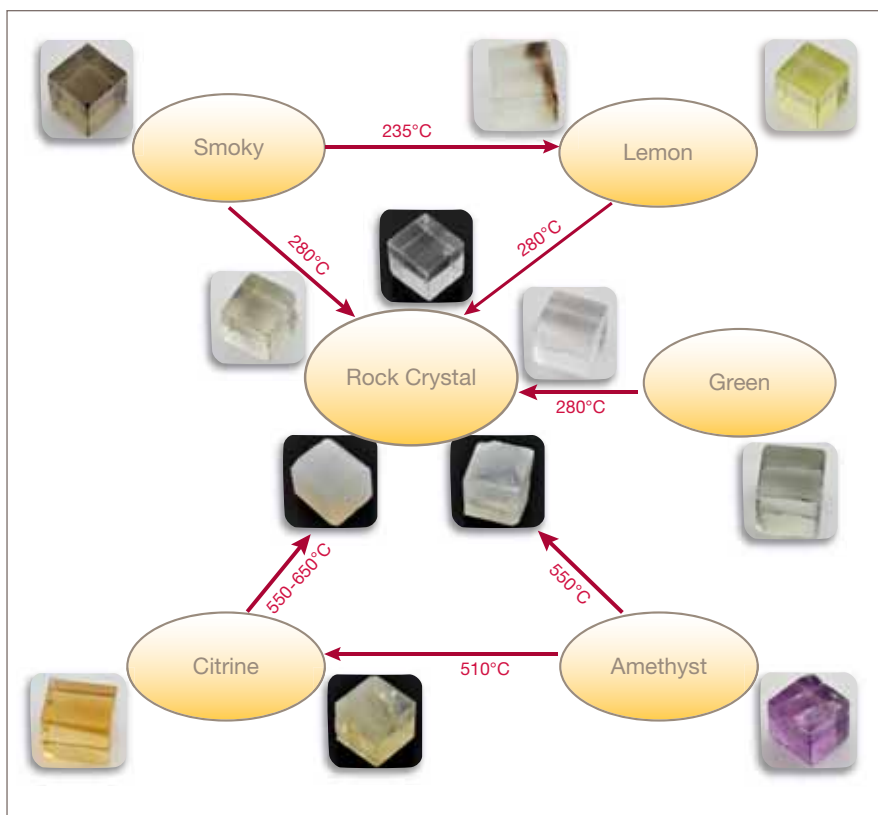
SPECTROSCOPIC EXAMINATION OF COMMERCIALY AVAILABLE QUARTZ VARIETIES: A GEMOLOGICAL PERSPECTIVE

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The lack of inclusions and visible growth features (color zoning) makes the separation of colorless natural and synthetic quartz quite challenging. Colorless quartz (rock crystal) can also be produced by heating other natural or synthetic quartz varieties, such as amethyst, citrine, smoky, green (prasiolite), and greenish yellow (lemon). Rock crystal is the purest variety of quartz, but it often contains Al³⁺ impurities for which the charge imbalance is compensated by a nearby interstitial alkali ion; this is a precursor for smoky quartz, which is produced by natural or artificial irradiation. Iron impurities result in green (Fe²⁺), yellow (Fe³⁺), or violet (Fe⁴⁺) colors.

Infrared spectroscopy provides useful data for differentiating between natural and synthetic quartz, while also identifying the original color variety. In our study, the OH, Al-OH/Li, Al-OH, Si-O/Al-OH, and Si-O related bands at ~3593, 3480, 3379, 3305, and 3198 cm⁻¹ consistently appeared in natural rock crystal, while the 3584, 3421, 3297, and 3198 cm⁻¹ absorptions were pre-



sent in synthetic rock crystal; the most important band for distinguishing natural from synthetic material was at 3480 cm^{-1} . IR data also help differentiate between natural and synthetic versions of other colored varieties and whether the color is natural or produced by heating.

IR AND UV-VIS SPECTROSCOPY OF GEM EMERALDS—A TOOL TO DIFFERENTIATE NATURAL AND SYNTHETIC STONES, AS WELL AS GEOGRAPHIC ORIGIN?

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Research on emerald's characteristics and origins is of great importance to the gem industry. We tested the usefulness of two spectroscopic methods to (1) distinguish synthetic from natural emeralds, (2) discriminate between the different provenances of natural emeralds, and (3) identify the various types of synthetic emeralds. Using UV-visible and Fourier-transform infrared spectroscopy, we investigated 133 emeralds of natural or synthetic origin and, for the natural stones, known provenance. Based on our spectroscopic observations, we were able to assign 78% of the emeralds to their proper origin. We identified every synthetic emerald and recognized all natural Colombian emeralds as well as all flux and hydrothermal synthetics. We also observed characteristic features in 86% of the Zambian emeralds.

EXTREME CONOSCOPY

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Conoscopy is an important yet sometimes challenging gemological technique for locating and identifying interference figures in gem materials. Using fixed polarizing filters, combined with mini- and micro-sized transparent, colorless spheres singly and in multiple arrays, demonstrates: (1) typical uniaxial, uniaxial quartz "bull's-eye," and biaxial conoscope images and their crystallographic relationships; and (2) uniaxial versus bull's-eye figures in Brazil law-twinned amethyst or ametrine.

Preparation—Uniaxial: Stack two sticky-backed polarizing filter sheets in crossed-polar orientation with the glue sides facing each other. Place polished quartz and tourmaline slabs (looking down the optic axis) on the stacked filters and trace their outlines. Cut the traced shapes from the marked filters and peel the protective plastic from the glue and non-glue sides. Next, fit and adhere the filters to opposite sides of each mineral slab, maintaining crossed-polar orientation. Each slab is now fixed with its own polariscope.

Preparation—Biaxial: Locate one optic axis in a danburite

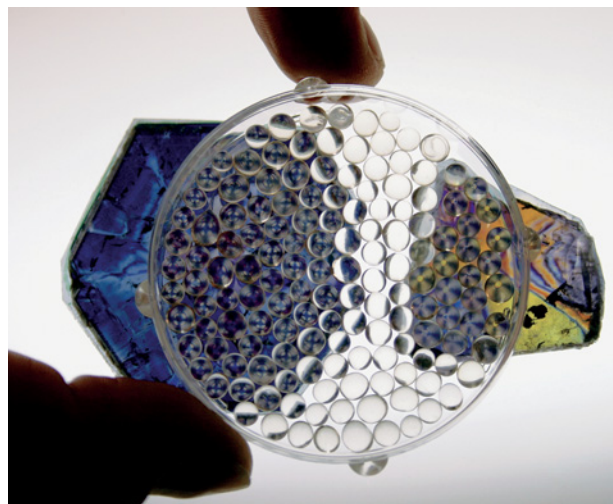
crystal by positioning it horizontally between crossed polars and rolling the horizontal crystal until a prism face exhibits interference colors. Adhere the fitted crossed-polarizing filters on this prism face and its opposite face. The danburite crystal is now also bound within a polariscope.

Sphere Array: Line the bottom of a plastic Petri dish with mini- or micro-sized spheres. This is now a single-plane, multi-conoscope unit for unaided or magnified viewing.

Process: Place the filter-bound specimens over a diffused white light source such as a pocket torch or light table. Interference colors will be evident. Alternately place larger individual spheres and the multi-sphere arrays over each specimen. Compare the various figures that appear in the spheres. This method is recommended as an adjunct to conventional conoscopy.

The many advantages of fixing specimens in a polariscope include: (1) easy specimen manipulation for better observation; (2) connection of crystal orientation and optic axes; (3) simple determination of optic figures; (4) observation of Brazil-law twinning; (5) the potential to demonstrate right- or left-handed twinning in quartz (with the use of retardation plates); and (6) relative ease of capturing photographic and video images of interference figures. Larger sizes of strained spheres (glass, plastic, or Biogel) that would normally exhibit notable strain within a polariscope show minimal strain outside the polariscope when used over the filter-bound specimens.

An array of mini-sized spheres shows multiple uniaxial interference figures across the entire surface of the twinned amethyst slab on the left. The ametrine slab on the right exhibits typical uniaxial figures in Brazil law-twinned zones as well as uniaxial bull's-eye figures in untwinned areas. Both types of figures are visible in the amethyst, showing that it can exhibit twinned and untwinned zones in the same crystal. Photo by S. M. Gumpesberger; specimens courtesy of the Royal Ontario Museum, Toronto, Canada.



DETERMINING THE CHEMICAL COMPOSITION OF GARNETS USING RAMAN SPECTROSCOPY

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Garnets are a group of minerals with diverse chemical compositions and a multifaceted impact on the geological and gemological sciences. Chemical composition is critical to the identity of a garnet's species, such as andradite (demantoid), grossular (tsavorite), almandine, pyrope, or spessartine. Garnet composition is typically determined using an electron microprobe or mass spectrometer. In recent decades nondestructive Raman spectroscopy has been used to identify crystalline materials by observing their vibrational modes. Forty garnets, representing all six major species, taken from RRUFF project samples (<http://rruff.info>), were analyzed to develop a technique that correlates the Raman modes of a garnet with its chemical composition. Chemistry was determined by electron microprobe, and Raman spectra were measured using a Thermo Nicolet Almega microRaman system or an open-access, custom-built Raman instrument. A correlation matrix was created to correlate the shifts in Raman peak position with changes in chemical composition.

This approach can characterize garnet samples with 15 chemical compositional variations using six Raman modes. The method was accurate to within 3% of the electron microprobe calculation of bulk chemical composition, and it correctly identified all species of garnet. This technique makes it possible to determine the chemical composition of garnets nondestructively and relatively inexpensively, and made the identification of garnet group species much faster and easier than with the use of microprobe analysis.

CIRCLE AND SPOT FORMATION MECHANISMS AND CHANGES IN LUSTER, COLOR, AND ROUNDNESS OF CULTURED PEARLS BY GRAFTING METHODS IN *PINCTADA MARGARITIFERA*

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This study investigated factors affecting the quality of cultured pearls, such as circles, spots, and irregular shape, luster, and color. Some pearl mollusks show phenomena similar to circle and spot marks on the nacreous part of their inner shell, and changes in shape, luster, and color have been reported by pearl-grafting technicians and farmers. Between 2006 and 2009, a total of 4,011 cultured pearls were examined for their quality, of which 828 with

circle marks were chosen for the experiments. As the pearl industry does not have a unified grading standard, the author adopted the GIA grading system. A GIA-educated pearl grading expert was employed to assess quality, and grafting operations were conducted by a highly regarded retired master technician.

The results indicated that circles most likely form during the first, or "virgin," cultivation. The harvest from regrafted *P. margaritifera* mollusks ("seconds") showed fewer instances of circling, and circles were less prominent.

It is widely speculated that circles form because of rotation or movement of the cultured pearl inside the pearl sac, and that circled products are found more often in younger, more muscular mollusks. According to this theory, the rotation or movement of the cultured pearl should produce non-linear or sinuous marks. This study found no such sinuous patterns among the several thousand samples examined, with only a few showing circles that crossed or overlapped. Virtually all had perfectly "ringed" or linear forms. The circle marks were directional, perpendicular to the axis of rotation, and parallel to one another. This suggests that an implanted piece of mantle tissue propagated directionally, and that the newly formed pearl sac could represent groups of directionally formed epithelial cells.

Thus, the author proposes that aligned groups of cells have similar or identical functions in nacre secretion capability, which develops into circle marks. This hypothesis would shed light on a century-old myth about circled pearl formation and possibly unite current theories on the mechanisms of mantle epithelium cell proliferation and gene-controlled nacre crystallization processes.

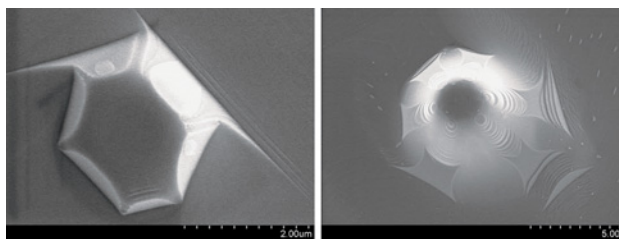
Another finding of this research concerns differences in formation between circles and spots: While most of the circles appeared to have originated during the virgin pearl formation, spots tended to occur in pearls cultured from mollusks that had been regrafted. The results from three years of consecutive grafting experiments further revealed that roundness increased in the "seconds" and "thirds" compared to the virgin cultured pearls, while luster and color tended to fade.

THE OBSERVATION OF DEFECTS AFTER THE PRETREATMENT AND SIMPLE HEAT TREATMENT OF RUBY

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Ruby is commonly pretreated to remove unnecessary impurities before heating. We have developed a hydrothermal pretreatment method, using a mixed-acid solution (10HF-3HCl-2H₂SO₄) at 200°C for 72 hours, that eliminated impurities faster than the process commonly used. The technique affected not only color and



After heat treatment, alumina particles with hexagonal or pyramidal shapes were visible on the surface of this ruby that had undergone pretreatment.

clarity, but also the weight of the stones after treatment.

We examined the surface features of rubies of various origins (Mozambique, Madagascar, Myanmar, Vietnam, Sri Lanka, and Cambodia, as well as a Verneuil synthetic ruby for comparison) before and after the pretreatment process, and then after heat treatment. After pretreatment, we observed several differences in visible surface defects and solubility according to sample origin and quality (i.e., the amount of inclusions and of hydrated alumina minerals such as diaspore, boehmite, and bauxite). The natural rubies showed various surface defects (etch pits, pores, and cracks) when viewed with high-magnification (SEM-EDS); the pores were formed by the dissolution of hydrated alumina impurities. FTIR analysis prior to pretreatment indicated that the higher-quality rubies contained less alumina impurities.

During hydrothermal pretreatment, the alumina was dissolved and precipitated on the surface as a visible white powder. After simple heat treatment at 1600°C, the alumina particles showed hexagonal or pyramidal shapes, depending on the quantity of Fe. For rubies with a higher Fe content, the particles took a pyramidal shape; low-Fe samples exhibited hexagonal pillars. We observed that, in addition to the formation of alumina particles, heating helped heal some of the etch pits, pores, and micro-cracks.

OPERATIONAL CONSIDERATIONS OF EDXRF, LA-ICP-MS, AND PHOTOLUMINESCENCE TECHNIQUES IN THE ANALYSIS OF PEARLS

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The gemological characterization of pearls requires knowledge of their internal structures (microradiography and/or computed microtomography) and chemical composition (in particular, Mn and Sr) to help differentiate between freshwater and saltwater environments. This information also plays a role in identifying the producing mollusks. Modern analytical techniques such as EDXRF spectroscopy, LA-ICP-MS, and photoluminescence (PL) are used to detect Mn and other trace elements at various sensitivities and sampling depths.

EDXRF spectroscopy, a nondestructive technique, typically provides semiquantitative or quantitative results for Mn and Sr

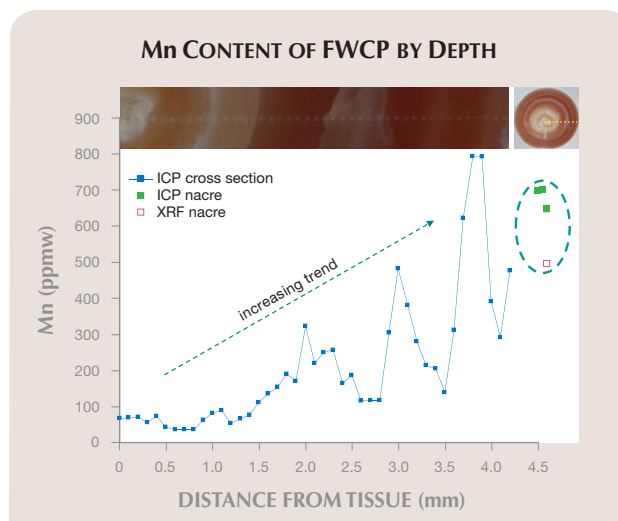
over a circular sampling area of 1–3 mm in diameter. The conventional technique of X-ray fluorescence imaging is capable of sampling through the whole pearl at elevated X-ray energy. However, the technique does not directly provide quantitative information on chemical makeup to differentiate pearls in the way that EDXRF permits.

LA-ICP-MS, which leaves tiny, submillimeter pits in the sample's surface, offers high sensitivity and covers a greater range of elemental concentrations. Yet it only samples the outermost layers of the pearl.

PL spectroscopy is known to be highly sensitive to trace amounts of elements down to the parts per billion (ppb) level. Laser-induced PL spectroscopy is a convenient extension of Raman spectroscopy during pearl analysis.

In this study, the detection depth of EDXRF was examined initially by placing a piece of lead (impenetrable to the X-ray beam) on sections of cultured pearls of various thicknesses. The results suggested a maximum penetration depth of about 1 mm. However, further tests on Akoya bead-cultured pearls proved that the actual detection depth for Mn was much shallower, at well below 500 µm. To illustrate the potential problems of this limited sampling depth, three freshwater non-bead cultured pearls were cut in half and elemental analysis was performed throughout their cross sections by LA-ICP-MS. The results showed unequal distribution of Mn concentration from the center to the surface of these cultured pearls. Moreover, the amount of Mn coincided with the samples' growth rings and color variations at regular intervals. This kind of information cannot be obtained if only the surface nacre is analyzed by EDXRF and

Natural variations in the amount of trace elements present within the internal growth structures of pearls are shown in this LA-ICP-MS data for Mn content taken from a cross-section of a freshwater cultured pearl.



LA-ICP-MS. Finally, a preliminary study was performed on the sampling depth of PL by placing a piece of ruby beneath the cultured pearl samples. The presence of ruby's characteristic luminescence peaks for thicker cultured pearl samples indicates that laser PL analysis occurs throughout the nacreous layers deep into the samples, unlike EDXRF and LA-ICP-MS techniques. The potential for laser PL to be a more useful technique in pearl analysis therefore exists.

In conclusion, these studies provide comparative findings on cultured pearls examined using the methods mentioned above, and show that some operational considerations should be taken into account particularly during quantitative data collection.

EXPERIMENTS ON ANCIENT GEM TREATMENT TECHNIQUES

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Many gem treatments commonly encountered today have been known, practiced, and documented since ancient times. In fact, some techniques for altering and improving the natural appearance of low-quality gems predate the gemological literature. These procedures, recorded as recipes, describe both treatments as well as methods to imitate valuable gems using ordinary materials.

Some recipes recorded in the early literature include very unusual ingredients that would not be considered as part of a scientific study today. There is a point in history where science had an unclear distinction from alchemy—between, roughly, the 13th and 20th centuries, “magical” and medicinal use of gems was more common than ornamental use. But contrary to general interpretation of ancients by our modern society, this approach was rarely seen before medieval times.

The ancient treatment techniques include heating, dyeing, oiling, and quench crackling. This study reviews some modern experiments using these recipes. Ancient gem-related texts such as Theophrastus' *On Stones* and Pliny the Elder's 37th volume of *Natural History* are the most notable documents. However, significant yet lesser-known ancient writings such as the Stockholm Papyrus from 400 AD and Al-Biruni's 11th century *In Knowledge of Precious Stones* contain gem treatment recipes that were the focus of this study.

Stockholm Papyrus and Pliny's *Natural History* give details of heat treatment of agates in honey to darken their color. As an early example of a gem treatment, this was widely practiced in Hellenistic and Roman eras to provide suitable carving material for engraving cameos. Schmidt (2009) demonstrated the steps of this procedure and proved that a combination of honey and controlled heating darkened the color and enhanced the layered appearance of agates. This particular experiment also verifies the

capability of ancient lapidaries in using locally available material rather than relying on imported agates, as otherwise suggested by many historians based on Pliny's writings.

Similarly, Al-Biruni gives a recipe for removing dark coloration in rubies. In order to test the recipe, J. Emmett (Crystal Chemistry, Brush Prairie, Washington; pers. comm., 2011) heat treated Mong Hsu rubies at 1100°C for 10 hours in air, precisely as described by the ancient text. The result was lighter and uniformly colored rubies.

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A GEMOLOGICAL COMPARISON OF THE TWO MAJOR OREGON SUNSTONE DEPOSITS

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Gem feldspar naturally colored by copper has been mined for many years in the state of Oregon and has come to be known as “Oregon sunstone.” Two areas produce almost all of this material. The first lies in the southern part of the state, near the small town of Plush. This is a large area in which there are many mines, the largest of which is the Dust Devil. The second site, located to the north, is a single mine known as the Ponderosa. The gem labradorite from these two sources is similar in many respects. Oregon miners, however, have long maintained there are significant differences. This study investigates what differences, if any, there are from a gemological viewpoint.

Physical Appearance: At both sites, the rough material occurs mostly as broken fragments. Many pieces have some unbroken surfaces that show evidence of dissolution. But whereas the Dust Devil feldspar is largely free of matrix, the Ponderosa rough often has a thin coating of opaque reddish brown material adhering to the surface.

Most of the samples recovered from the two deposits are light yellow with no schiller. The Dust Devil material is a deeper yellow and mostly transparent. The Ponderosa material is typically pale yellow—almost colorless—and semitransparent. Both sites also produce yellow stones with copper schiller, as well as red, green, and bicolored material (with and without schiller), but the Ponderosa mine yields a rare deep red feldspar that this author has not seen from the Dust Devil.

Inclusions: Aside from the persistent cloudiness of many Ponderosa specimens, there is no apparent difference in the inclusion suites of stones from the two areas.

Chemistry: Samples from both mines fall within the labradorite compositional range for plagioclase. Yet the Ponderosa material plots closer to bytownite, sometimes even

crossing the border into that species, while the Dust Devil stones plot closer to the middle of the labradorite range. These groupings are distinct but do show a small amount of overlap.

Conclusion: From these and other observations, we know there are clear differences in the gem feldspar from these two locations. These differences may help in understanding the complex formation of these stones, and in detecting and anticipating feldspar treatments.

CHANGES IN COLOR AND OPTICAL PROPERTIES OF VARIOUS SAPPHIRES BY ELECTRON-BEAM IRRADIATION

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Sapphire may occur in various colors as a result of intervalence charge transfer (IVCT) depending on the type and combination of transition metals (e.g., Fe, Ti, and Mg) that substitute for Al. Iron may exist in a ferrous (Fe^{2+}) or ferric (Fe^{3+}) state in sapphire. Yellow is caused by Fe^{3+} existing singly or as a pair; charge transfer between Mg^{2+} and a trapped hole can also cause yellow color. Titanium alone cannot produce color, but if iron and titanium atoms are present, a sapphire will be blue. In general, the origin of the blue color is thought to be generated by IVCT between Ti^{4+} and Fe^{2+} , while pink, orange, and green colors are believed to originate through the interaction of the blue color from the IVCT of Ti^{4+} and Fe^{2+} , and the yellow produced by the IVCT of Fe^{3+} - Fe^{3+} (Burns, 1981).

In this study, we investigated changes of color and spectral characteristics in six colors of sapphire (colorless, blue, orange, yellow, pink, and green) after electron-beam irradiation. The irradiation was performed with an energy of 10 MeV and a dose of 3×10^{17} electrons/cm². After irradiation, the colorless, blue, and pink groups (which had somewhat lower Fe content by wavelength-dispersive XRF analysis) changed from their initial color to dark yellow; the green, orange, and yellow groups did not. Interestingly, Ti was not detected in any of the samples by XRF, but Si^{4+} (a donor ion) was detected in all samples. The Si content of the colorless, blue, and pink samples was very low compared to the green, orange, and yellow groups. The important factor is the total amount of Si and Fe within the sapphires of each group. In the case of the colorless, blue, and pink groups, IVCT takes place between the Fe^{2+} and Si^{4+} ions, but since there are fewer Si^{4+} ions to consume than in the green, orange, and yellow groups, it is likely that many extra Fe^{2+} ions remain even after interacting with Si^{4+} ions. The remaining Fe^{2+} ions could not influence the color of the sapphire until electron-beam irradiation transformed them to Fe^{3+} , producing dark yellow coloration.

BEFORE IRRADIATION AFTER IRRADIATION



Shown here are the effects of electron beam irradiation on various colors of sapphire.

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THE GIA GEM PROJECT—AN ONLINE RESOURCE OF INFORMATION ON GEMSTONES

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In 2005, GIA acquired the gem collection of the eminent Swiss gemologist Dr. Edward J. Gübelin (1913–2005). The collection consists of more than 2,800 samples representing 225 different minerals and other gem materials. Dr. Gübelin assembled it over a span of six decades (from ~1940 to 2000) by purchases from knowledgeable dealers and during trips to major gem-producing localities. The items in the collection are now being systematically documented to expand GIA's gem information database.

To help fulfill its mission as a public-benefit organization, and to support its students and staff, GIA is making the contents of the Edward J. Gübelin collection database available on its website (www.gia.edu/gia-gem-project). At present, data on 330 gemstones—including beryl, garnet, spinel, tourmaline, and zircon, among others—can be viewed, and additional groups will contin-

ue to be posted. Each listing, also available as a downloadable PDF document, contains a photo of the gem, standard gemological properties, a photomicrograph of an interesting internal feature, and several types of spectra (visible, infrared, photoluminescence, and Raman, along with EDXRF qualitative chemical analysis). Also provided is an explanation of the data collection procedures used for this project.

This is the first publicly available online database that includes gemological, spectroscopic, chemical, and photographic data gathered on a wide variety of natural gemstones. Although valuable mineral databases do exist, they often do not provide essential information needed by gemologists, and the books published on minerals and gems generally represent compilations of information. By presenting entire sets of data collected from each gem sample, obtained using consistent collection procedures and analytical instrumentation, this database will allow a better correlation of gemological properties. With the preservation of the Edward J. Gübelin gem collection at GIA, samples will be available for characterization as new analytical instrumentation or techniques are introduced, or as new gemological studies are needed.

SPECTROSCOPIC CHARACTERISTICS OF SOME GEM TOURMALINES

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In the gem trade, jewelry-quality tourmalines are usually defined by color rather than by chemical composition or mineral species. Five species of tourmaline are commonly used for gems and jewelry: elbaite, dravite, liddicoatite, schorl, and uvite. In this study, yellowish green, greenish blue, and green to dark green tourmalines were separated into elbaite and dravite using photoluminescence (PL), EDXRF, and in some cases UV-Vis-NIR spectroscopy. The PL spectra of dravite displayed dominant peaks from about 680 to 690 nm (Cr^{3+} and Fe^{3+}), while the elbaite showed main peaks at about 627–633 nm (V^{3+}). The PL data were consistent with the EDXRF chemical data, in that dravite always had a higher Mg content than elbaite. With UV-Vis-NIR spectroscopy, dravite showed strong absorption peaks at ~437 and 606 nm (V^{3+}), whereas elbaite displayed strong absorption from ~715 to 730 nm (Fe^{2+}). For gemologists, these spectroscopic data can be used as preliminary diagnostic tools for differentiating elbaite and dravite.

NEW ARTIFICIALLY ASTERIATED GEMSTONES

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About 40 different gems are known to display asterism (and several trapiche varieties can show fixed stars). The minute, oriented

inclusions of these gems are able to create stars with four, six, eight, 12, 18, or even 24 rays. In addition to the well-known stones with four- and six-rayed stars, this author has encountered some rare new varieties of asteriated gems (color-change garnet, chrysoberyl, and rutile).

Synthetic star corundum has been known since about 1947, and diffusion-treated blue star sapphires first appeared on the market during the early 1980s (Nassau, 1981). The use of artificially etched crystal faces or scratched metal plates (at the base of the cabochon) to create asterism was documented as early as the first half of the 19th century. A relatively new imitation of asterism—stones with stars created by scratching fine lines on the upper dome of the cabochon—appeared about 10 years ago. Such artificially asteriated gems mentioned in the literature include cassiterite, chrysoberyl, garnet, rutile, samarskite (scheelite?), and sinhalite (McClure and Koivula, 2001); black tourmaline (Schmetzer and Steinbach, 2002); and sphalerite (Hyršl and Steinbach, 2009). Artificially asteriated examples of pyrite, iolite, green garnet, chrome diopside, green tourmaline, and sapphire are described here for the first time.

Features used to identify the scratching include:

- Unnatural appearance of the star.
- Lack of oriented, acicular inclusions in the stone.
- Oriented scratches on the surface of the cabochon.
- Incomplete, crooked, or asymmetrical rays of the star.
- So-called “satellite beams” on the stone.
- Extra rays incompatible with the crystal symmetry.
- The star appears sharpest when the camera is focused *above* the surface of the cabochon.

The star in this 4.57 ct iolite was created by scratching fine oriented lines on the dome of the cabochon. Photo by M. P. Steinbach.



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EXPERIMENTS ON HEATING OF BLUE SAPPHIRES WITH BERYLLIUM

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The Gem and Jewelry Institute of Thailand has conducted experiments on the beryllium-diffusion treatment of blue sapphires. Rough corundum samples from both metamorphic and basaltic deposits were collected; they ranged from light to medium blue. Eight to 10 samples were used in each experimental batch. The stones were analyzed specifically for their trace-element chemistry using LA-ICP-MS and other spectroscopic methods such as UV-Vis and FTIR. These properties, as well as visual characteristics (color, zoning, and internal features), were recorded before and after each step of the treatment.

The sapphires were first heated in the presence of beryllium oxide to 1650°C in an electric furnace for 50–80 hours. Almost all the metamorphic samples turned yellow, greenish yellow, or yellow with blue patches; the latter could be further heated to achieve a greenish yellow color. For the most part, the basaltic sapphires showed mild reactions to the experiment, but some of the medium blue samples turned very dark blue.

The sapphires then underwent further heating without beryllium in a reducing environment at 1200–1500°C for 12–24 hours, and were left to cool in the furnace. Their resulting colors were blue, greenish blue, and (especially in the basaltic stones) dark blue. These experiments showed that not all sapphires turn blue with beryllium-assisted heating under these experimental conditions, though longer heating might be needed.

The origin of the corundum was critical to the outcomes, as metamorphic sources yielded better results. Several of the samples showed internal features resembling those seen in Be-diffused blue sapphires in the marketplace.

It is likely that heating with the assistance of beryllium better dissolves mineral inclusions in the samples, especially Ti-bearing phases such as rutile. Such heating also appears to promote a better distribution of blue color-causing elements such as Ti and Fe. Subsequent lower-temperature heating in a reducing atmosphere helps produce blue coloration, and LA-ICP-MS analyses showed that some of the beryllium is driven out of the samples during that step.

NEW TECHNOLOGIES AND INSTRUMENTATION

INCLUSION MAPPING IN DIAMONDS

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Inclusions are part of the life cycle of diamond cutting and evaluation, from the marker's decision on how to cut the stone through the polishing process and clarity grading after the diamond is fully polished. In the rough stage, a frosted surface may obscure the inclusions or conceal their true location. To view the inclusions, the marker polishes flat “windows” on the surface. However, the polisher cannot judge the penetration depth and the final weight of the diamond if he were to polish it out. With regard to polished diamonds, the current method of documenting the structure and location of inclusions relies on an experienced gemologist using a quality microscope or loupe, and the results are often mixed.

Sarin has systems for accurate 3D mapping of the diamond surfaces (rough and polished) and has introduced a new system, Galaxy, to map their inclusions. It covers all types of inclusions: cracks, clouds, crystals, etc., both transparent and opaque. It scans most types of diamonds, from clean to heavily included, as well as transparent, frosted, and even slightly coated. It detects inclusions down to VS size, and even VVS in many cases. As a result, the planner can maximize the value of the polished diamonds to be cut from the rough, while the polisher can better evaluate the option of polishing out inclusions to improve clarity. It also greatly speeds up the clarity grading process by detecting all significant inclusions and generating a 3D model of their distribution in the diamond, allowing the gemologist to focus on assigning a grade.

SYMMETRY: FROM ASSESSMENTS TO METRICS

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The symmetry grading of polished diamonds is based on roundness, variation in angles and alignments, and other parameters. Non-contact measuring systems such as the Sarin DiaMension

allow calculated 3D modeling of the data required to evaluate symmetry with regard to these manufacturing parameters. However, current systems for 3D modeling are not accurate enough to provide reliable, repeatable values. The recently introduced Sarin DiaMension HD uses a high-resolution camera, advanced optics, improved calibration, and a sophisticated algorithm to generate a 3D model of a diamond's shape. It enables the automatic symmetry grading of a diamond in the same manner a proportion scope was once used to evaluate cut.

There are two challenges in assessing symmetry. One is evaluating how well the facets meet (their "pointing"). A standard round brilliant has five types of pointing and a total of 40 corners where facets meet. The asymmetry of the pointing is defined by the diameter of the circle that encloses the meeting point. Once the values for each pointing are known, a grading laboratory can set the upper and lower limits for each grade and pointing type. With these limits, a symmetry grade can be assigned to the 40 individual meeting points. The second challenge is to assign an overall symmetry grade. This is determined by the lowest grade of the various parameters (roundness, table off-center percentage, culet off-center percentage, table/culet alignment, table size variation, crown height variation, pavilion depth variation, girdle thickness variation, crown angle variation, and pavilion angle variation) or a combination of grades. The Sarin device provides both the means and metrics to measure the symmetry features, and a tool to automatically determine the overall symmetry within a grading laboratory's defined parameters.

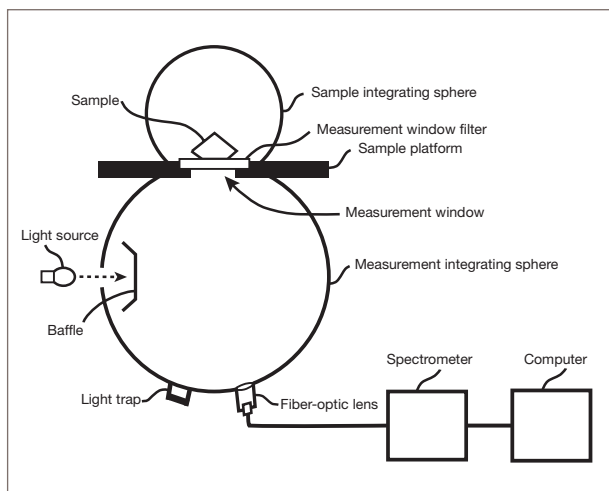
INSTRUMENTAL COLOR MEASUREMENT AND GRADING OF FACETED GEMSTONES

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A dual integrating sphere spectrometer with artificial intelligence (including neural network and fuzzy logic algorithm software) has been developed for the color measurement and color grading of faceted gemstones using the Universal Color Grading System. The spectrometer can also accurately grade fancy-colored diamonds using a modified GIA grading system, as well as green jadeite according to Chinese grading standards.

The dual integrating sphere optic arrangement includes measurement and sample integrating spheres, and a sample platform with a measurement window. CIE Standard Illuminant D65 and the CIE 1931 2° Standard Observer are used. The illuminating/viewing geometry is diffuse/0 degree (d/0) to simulate the geometry of human visual color grading. The measurement integrating sphere provides diffused light to illuminate a gemstone face-down on the sample platform, and the sample integrating sphere serves as a white background. The light reflected from the table plus the transmittance light reflected back through



This dual integrating sphere spectrometer was developed for color measurement and color grading of faceted gemstones.

the stone by the sample integrating sphere is collected by a lens at the bottom of the measurement integrating sphere. The collected light is sent to the spectrometer to measure the spectral reflectance.

The color grading software includes a neural network, a color calculation routine, a CIELAB-to-color-nomenclature look-up table, and a fuzzy logic algorithm. The trained neural network collects physical and optical properties, and outputs parameters for the spectrometer to measure the spectral reflectance. The color calculation routine determines the average color from the measured spectral reflectance. The software then checks the look-up table to determine its average color grade within the Universal Color Grading System. Based on the parameters from the neural network and the average color, the fuzzy logic algorithm determines the true color grade. The Universal Color Grading System optimizes the arrangements of color grades in CIELAB color space. The System has a minimum number of boundaries with a maximum color grade in three color dimensions. Importantly, all color grades are also optimized so that the largest possible color difference of each color grade is minimized. The spectrometer can directly measure visible fluorescence, since the illuminating light is in the whole visible wavelength range. The spectrometer can also accurately measure the color of gemstones that have visible fluorescence, such as the red color of ruby.

AUTOMATED REAL-TIME SPECTRAL ANALYSIS FOR GEMSTONES

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Spectra are now routinely collected in gemological laboratories as nondestructive analytical measurements. They can be vital to revealing the geographic source, color origin, and identity of gem

materials. As treatments and gem synthesis techniques become more sophisticated, gemologists are required to search for increasingly subtle clues that can distinguish natural from synthetic and treated gem materials. Therefore, gems are often subjected to several types of spectroscopy to reveal the histories hidden in their defect configurations and chemical compositions. The most effective testing method is to gather sets of known samples, collect their spectra, and then analyze the peaks in those spectra using advanced chemometric techniques. The confluence of data extracted from the spectra of unknown samples can then be analyzed, and the conclusion will have a quantifiable confidence.

To aid in that analysis, we have developed an innovative peak-finding/fitting computer program called Spectralysis, which can process spectra on an industrial scale. The program can also handle complex spectra, which we define as those having more than 60 peaks, including numerous convoluted peaks, a combination of broad and sharp peaks, and background fluorescence. The analysis extracts quantitative results, enabling users to draw substantiated conclusions regarding origin identification (e.g., natural, synthetic, or treated).

The program performs batch processing so human interaction for each spectrum is unnecessary. This algorithm thus allows researchers to spend less time and resources on data mining and processing, while opening new avenues of research by highlighting previously unknown relationships between peaks.

The variation in peak width and height between Spectralysis and a manual peak-fitting program such as Grams is generally less than 5%. Our experience has shown that an error of up to 10% can be introduced by human variation in calculating the full width at half maximum (FWHM) in Grams. Most importantly, Spectralysis automatically retains peak parameters such as height and area for searching, categorizing, and correlating with other spectra using chemometric methods.

The functionality described here should not be confused with that of library-matching programs—Spectralysis is compatible with them nonetheless—that can distinguish ruby from garnet, for example, but generally not natural from treated gemstones, which is the intended scope of our software. We have demonstrated the program's effectiveness using nonproprietary spectra culled from the RRUFF database (<http://rruff.info>).

DETERMINING THE PROVENANCE OF GEMSTONES USING THE MATERIALYTICS SEQUENCING SYSTEM (M2S)

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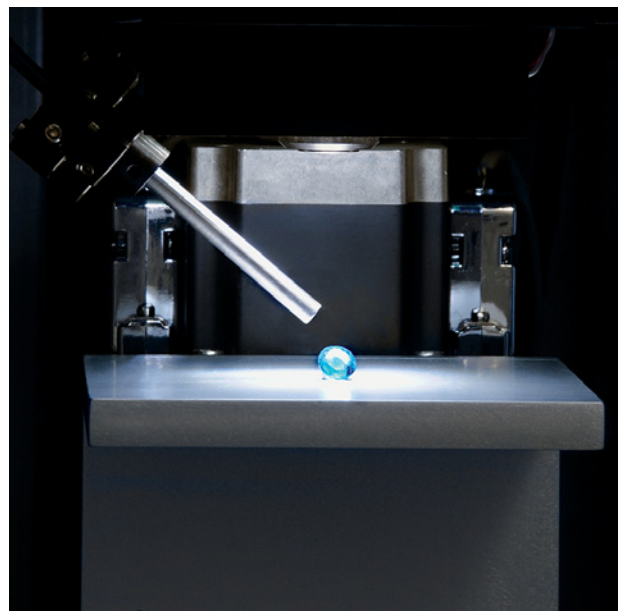
A new quantitative process, the Materialytics Sequencing System (M2S), increases accuracy in identifying the provenance of certain geomaterials, including (but not limited to) beryl, corundum, gold, and tourmaline. Using laser-induced breakdown spectroscopy (LIBS) and unique pattern-recognition software, this system can match these geomaterials to their country of origin with greater than 95% accuracy.

An extensive inventory of specimens—more than 42,000 and growing—has been collected and maintained; the integrity of this sample set is crucial to provenance identification. The Materialytics inventory contains samples from six continents, more than 60 countries, and 225 localities in all.

The M2S system consists of dual Nd:YAG lasers (266 and 1064 nm), an intensified CCD camera, an Echelle spectrometer, and computer software designed to maximize the signal obtained from a sample while minimizing the traces of testing. The laser ablates a small area of the sample, producing a microplasma that emits light in the 200–900 nm range. This light is collected by more than 40,000 channels of the spectrometer. These 40,000 dimensions are then analyzed using pattern recognition software that compares the signature of an unknown specimen to a large database of signatures from thoroughly documented specimens.

The interplay between the variability and commonality of the data from crystal to crystal, mine to mine, mining region to

This blue topaz is shown inside the LIBS chamber of the Materialytics Sequencing System (M2S). Photo © Materialytics.



mining region, and country to country requires a combination of statistical pattern recognition methods (principal components analysis, maximum redundancy analysis, partial least squares, and Bayesian networks) to achieve consistent results over a wide range of samples. M2S integrates these various methods into a single computer program that adapts to each sample, based on the nature of the data, and does not require any human intervention.

RECENT ADVANCES IN SYNTHETIC SAPPHIRE GROWTH

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Hundreds of tons of synthetic corundum are produced annually. This demand is fueled in part by high-technology applications and has driven innovations in sapphire crystal growth techniques. These improvements have resulted in the production of larger, higher-purity, and more defect-free synthetic sapphire material. Traditional crystal-growth methods employed for the production of gem-quality synthetic sapphire and ruby are now being joined by several other techniques—including edge-defined film-fed growth (EFG), heat exchanger method (HEM), Kyropoulos, vertical horizontal gradient freezing (VHGF), and controlled heat extraction system (CHES)—in the quest for larger, more perfect colorless synthetic sapphire.

EFG works by pulling melt through a shaped die in an evacuated furnace. The die is placed at the top of the melt, the melt wets the die through capillary action, a seed is dipped into the melt at the top of the die, and a shaped crystal is drawn upwards (Harris, 2004).

The HEM involves no movement. The seed is placed in the bottom of a crucible, and the filled crucible is evacuated and resistively heated. A low flow of helium is used to keep the seed from melting. The furnace temperature is held constant through the entire growth cycle. When growth is complete, the furnace is slowly cooled and the crystal is annealed *in situ*. The lack of motion and long growth time contribute to low dislocation density (Harris, 2004).

Kyropoulos growth involves seeding an inductively heated melt from the top, rotating the seed and crystal during growth, and crystallizing the melt in the crucible by decreasing the temperature (Dobrovinskaya et al., 2009).

The VHGF method, a variation of vertical Bridgeman growth, also involves no motion of the melt or crucible. The resistively heated melt is seeded from the bottom and has its extremely small vertical and horizontal temperature gradients tightly controlled, resulting in very low dislocation densities (Ahn, 2011).



Rubicon's first synthetic sapphire grown by the Kyropoulos method at their new plant in Batavia, Illinois, measured ~30 cm in diameter. Courtesy of Business Wire.

The CHES technique maximizes large-diameter cylindrical synthetic sapphire. The melt is produced and homogenized over a significant period under vacuum, is seeded from the bottom, and the crucible is vertically translatable. Also movable are the gradient control device and seed-cooling component. To induce crystallization, the melt is cooled from the bottom and the seed is cooled with He, Ne, or H (Gupta et al., 2010).

Most of these new techniques employ conditions that are not ideally suited to the growth of synthetic ruby and colored sapphire. But with the availability of increasing amounts of synthetic sapphire from these continuously improving techniques, it is helpful to have some basic familiarity with these methods and the material produced from them.

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PROVENANCE OF RUBIES AND SAPPHIRES: AN APPLICATION OF LASER-INDUCED BREAKDOWN SPECTROSCOPY (LIBS) AND ADVANCED CHEMOMETRICS FOR THE GEM INDUSTRY

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Rubies and sapphires totaling 572 samples of known origin from 24 deposits in 12 countries (Afghanistan, Australia, Greenland, India, Kenya, Madagascar, Myanmar, Pakistan, Sri Lanka, Tanzania, the United States, and Vietnam) were analyzed using an Ocean Optics 2500+ LIBS system. A 1064 nm Nd:YAG nanosecond laser was focused on a small area of each stone and pulsed at 120 mJ to ablate the sample, forming a short-lived, high-temperature plasma. As excited electrons decayed back to their stable configurations, photons were emitted and transmitted via an optic fiber to a spectrometer that separated the light into its constituent wavelengths, each of which corresponds to a specific element. Analyses were performed in an argon atmosphere to enhance the signal and minimize traces of testing. Average ablation craters were approximately 200 μm diameter; LIBS systems can be customized to minimize damage. Each stone was analyzed 30 times. Raw spectra were processed with a pair of advanced chemometric techniques: principal component analysis (PCA) and partial least squares (PLS) regression using Unscrambler software. PCA was used to simplify the dataset from 13,700 dimensions (each wavelength measured) to two to four dimensions by



These sapphire crystals (0.08–0.40 g) from Ratnapura, Sri Lanka, were analyzed by LIBS. Courtesy of Materialytics.

generating meaningful combinations of wavelengths (elements).

PLS regression models were calculated to characterize half the sample set (trainers). The trainers defined chemofacies, or chemically distinct datasets, which could be separated using the algorithm developed in this study. Because each deposit defines a unique chemofacies, it is possible to predict the provenance of the samples not used in the calculations (verification samples). Using the algorithms developed, tests of 122 verification sapphires and 164 verification rubies yielded correct identification rates of 93% and 90%, respectively. Misidentified samples were the result of poorly characterized chemofacies due to small sample sets. This work demonstrates that the provenance of rubies and sapphires can be determined through chemometric analysis of LIBS spectra.

BUSINESS TRACK

“PIGEON’S BLOOD” RUBY AND “ROYAL BLUE” SAPPHIRE: COLOR STANDARDS FOR THE GEM TRADE

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The Gem and Jewelry Institute of Thailand (GIT), with the cooperation of the Thai Gem and Jewelry Traders Association and the Chanthaburi Gem and Jewelry Traders Association, has

developed a quality assessment system for colored stones, specifically gem corundum. This system considers three major factors: color, clarity, and cut. Research has been conducted since 1999, and the assessment system has been continually refined through input from gem traders and gemologists. The GIT has established colored stone master standards for eight varieties of corundum, including ruby and blue, padparadscha, yellow, pink, purple, orange, and green sapphires. These master stones are oval shaped and at least 0.50 ct each.

The GIT’s standards are based on the Munsell system. The locally-used common color names were converted to the Munsell color codes, which were then modified so that they can be better understood by relying on the color code chart of the ISCC-NBS (Inter-Society Color Council—National Bureau of Standards) system. Moreover, the Munsell color codes can be converted into color notations in two CIE (Commission Internationale de l’Éclairage) systems, CIE L*U*V and CIE L*a*b, that are widely

used in spectrophotometer and other colorimetric equipment.

In addition, the historic terms *pigeon's blood* ruby and *royal blue* sapphire are still ambiguous to a number of traders and certainly unclear to most consumers. Such confusion has impeded potential buyers. Therefore, the GIT's comprehensive research has also focused on standardizing these color descriptors. A color master set of pigeon's blood rubies was established, consisting of 10 master stones in the vivid red range with intense color and medium tone. The color master set of royal blue sapphires contains 10 master stones in the vivid blue range with intense color and medium-dark tone.

These standards for pigeon's blood ruby and royal blue sapphire have been successfully implemented to promote the sale of Thai gemstones both domestically and internationally since 2008.

"TOO PRECIOUS TO WEAR": THE ROLE OF THE JEWELRY INDUSTRY IN CORAL CONSERVATION

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Coral reefs are the most diverse marine ecosystems, second only to tropical rainforests in terms of biological diversity, supporting more than 5,000 known species. Historically, an estimated nine million marine species, or a third of all marine life, lived on the shallow-water coral reefs. But corals and coral reefs throughout the world are being threatened by climate change, ocean acidification, pollution, overfishing, and consumer demand for this attractive material in jewelry and home décor items. Red and pink corals are among the most valuable and widely traded of these species. With the loss of habitat and the disappearance of precious coral from shallow-water reefs, extraction of red and pink corals from deep-water sources for jewelry use poses one of the greatest threats to deep-water reefs. But it can be remedied through changes in the marketplace and consumer behavior. Leaders in the jewelry and home décor industries can help reduce

demand for precious corals by refusing to incorporate them into their designs. Tiffany & Co. and other jewelers are participating in an initiative led by SeaWeb, a nonprofit ocean conservation organization.

SeaWeb's "Too Precious to Wear" campaign seeks to reduce the use of coral as a gem material by:

1. Highlighting the threats posed by consumer demand and an unregulated international coral trade.
2. Working with influential jewelers and designers to bring together leading voices for coral conservation.
3. Raising awareness of coral alternatives that celebrate the ocean without harming it.

The jewelry industry is in a unique position to help prevent further loss to red and pink coral. By simply becoming aware of the issue and looking to corals as an inspiration in jewelry designs, but not as part of the jewelry—leaving vital corals where they belong—designers and retailers can make a difference.

MARKET TRENDS IN A CHANGING GLOBAL ECONOMY

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Emerging markets worldwide have had a significant impact on gemstone prices. The United States has historically been the number one consumer of gemstones, driving prices up or down. This has changed, and we are now seeing countries such as China and India influence prices. The U.S. recently experienced its worst recession in 80 years, and demand for fine gems practically halted there over the past two years. One would have expected gem prices to plummet due to the serious lack of demand. Yet we saw increases, in some cases quite dramatic. The U.S. was no longer dictating the market.

Another key factor that has kept prices for colored stones high is the significant reduction in mining activity. While mining costs increased, overall global demand slowed, thus there was little incentive to keep mines operating. As shortages arose for some gems, the

Red coral (left) is being unsustainably harvested and worked into products such as coral beads (right, 1.3 cm long each) for the international jewelry trade. Alternatives to real coral should be utilized to reduce pressure on this species. Photos by Juan Cuetos/Oceana (left) and Ernie Cooper/World Wildlife Fund (right).



demand from emerging markets continued to push prices up.

Top-quality ruby has always been scarce, and prices have historically been strong and rising. With increased treatments of commercial material and global demand for finer goods, prices have surged even higher in recent years. Premiums for unheated rubies over heat-treated material continue to rise. Although unheated rubies can come from multiple locations, the main source of interest is Myanmar. Despite the U.S. embargo, prices increased dramatically in the past five years mostly due to emerging markets and demand from countries such as China and India.

Prices for blue sapphire dropped in the mid- to late-1990s due mainly to the large production from Madagascar. With the strong worldwide demand and the same economic factors, we are seeing recent price increases for blue sapphire, especially in finer qualities.

Prices for emeralds are rising with better demand in Europe and Asian markets and the weakness of the U.S. dollar against Colombian and other currencies. Also, the maturing attitude toward treatments of emeralds has reduced fears and increased the appetite to buy them.

While we are seeing a gradual return to buying in the U.S., the long-term projection is that cyclical changes will result in at least a partial return to a stronger U.S. economy and more prominent influence on the global gem markets. There is a spreading of wealth globally, with emerging and transitioning economies that did not exist a decade ago. At the same time, we are seeing a demographic shift toward younger consumers outside the U.S. While the U.S. will still have an influence on world gem prices, it will not be as strong as in the past.

Changing premiums on 1 ct Burmese rubies, unheated.

	Commercial	Good	Fine	Extra Fine
2006	0% to +75%	+50% to +75%	+50% to +75%	+50% to +75%
2010	0% to +125%	+75% to +125%	+75% to +150%	+150% to +250%
2011	0% to +150%	+125% to +175%	+125% to +200%	+200% to +300%

GEMSTONE COLOR AS NATURE'S PALETTE: VAN GOGH'S COMMENTARY ON A 111 CT STAR SAPPHIRE AND OTHER GEM-QUALITY CORUNDUM

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The shimmering beauty of blues, yellows, reds, and pinks in gemstones is reminiscent of masterpiece paintings. Vincent Van Gogh's remarkably vivid blues in *The Starry Night* have captivated



The application of color in the visual arts and in nature shows many interesting parallels. Both the Starry Night Sapphire, a 111.96 ct unheated Burmese gem shown here (and recent recipient of a GIA Monograph) and its namesake Van Gogh painting evoke a celestial feel rendered through variations of blue coloration. Although expressed through entirely different media, the messages conveyed by these works of art are remarkably similar. Photo by Robert Weldon.

viewers for the past century. We examined a 111.96 ct Burmese star sapphire with a similar color.

Sapphire owes its color to traces of titanium and iron. The depth of color often varies according to the viewing angle and the inclusions in the stone. For example, the nature and orientation of color banding in sapphire greatly influence the face-up color. The same intense parallel banding of color can be seen as a painting by Mother Nature. Van Gogh's brush often painted feverish, nearly parallel swatches of color, as also illustrated in the 111 ct Burmese sapphire.

Ruby is colored by trace amounts of chromium. The color of a classic Burmese ruby can evoke the shade of red seen in Van Gogh's *The Night Café*. Chromium present in lesser concentrations uses softer brushstrokes, imparting the delicate pink prized in padparadscha sapphires, which can also be seen in the vase of flowers in *The Night Café*.

AN ANALYSIS OF THE DEVELOPMENT AND TAX POLICY OF CHINA'S GEM INDUSTRY

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Over the past three decades, China's decision to open itself to trade with other nations has led to rapid economic growth and a rise in the number of Chinese families with high net worth. With this prosperity, China has become the world's third-largest consumer of luxury goods, according to Goldman Sachs,

accounting for 12% of global consumption. By 2015, that figure is expected to rise to 29%, with China surpassing the United States and Japan as the most important luxury player. China is already estimated to be the world's largest jewelry market, and the expansion of its gold market has attracted more and more high-end brands from overseas. As a result, it is playing an increasingly significant role in the international jewelry trade.

Within this context, it is important to study the impact of the Chinese government's policies with respect to the country's gem market and its future. A newly imposed domestic tax on the gem market, 5% for gold, silver, platinum, and diamond jewelry or diamonds, and 10% for other expensive jewelry or jade, will be a huge challenge in the coming years. Although the initial aim of levying a tax on the gem market is to limit luxury consumption by the wealthy and reduce the income gap between rich and poor, in practice the taxation on these gem products has already had a larger effect on average consumers than wealthy ones. The tax may bring changes in consumption by middle-class consumers, leading to lost tax revenue and reduced financial support for fair income allotment by the government. It may also shrink the gem market and limit the growth and development of China's gem industry.

MINERAL COLLECTORS—AN OVERLOOKED GEM MARKET

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Although numbers are not readily available, mineral specimens are a multi-million-dollar-per-year business. Fine mineral specimens often sell for tens of thousands of dollars. Gem minerals sell for a premium over non-gem minerals, with some specimens offered for millions of dollars. Most dealers in gem rough fail to take advantage of this market. To do so, they must understand which factors mineral collectors care about, and which gem qualities are less important.

Ideally, a mineral specimen should have sharp crystal faces, including a well-formed termination. It should appear complete from at least one viewing direction. Crystal faces should be lustrous and the edges undamaged. Attached matrix is desirable. Color and internal clarity are secondary factors. The most common undesirable feature in a specimen is visible damage, though sawn or polished crystal surfaces are considered worse than broken ones.

Although a mineral specimen should appear completely natural, most undergo cleaning. Treatments such as repair and oiling should be disclosed. Drastic treatments (e.g., dyeing, applying colored oils, and irradiation) detract from a specimen's value. Mineral specimens can be "faked" by artificial assemblage and synthetic overgrowths; fakes have value mainly

as curiosities.

A mineral specimen should have accurate locality information, at the county/state/country level. In general, the more specific the information is (such as mine, stope, or pocket, and date of collection), the better.

Collectors prefer to acquire specimens they can examine in person. For this reason, many specimens are sold during regional, national, or international mineral shows, through private transactions, or at natural history auctions. Mineral dealers also have physical stores, catalogs, and internet sites.

How can a gem dealer tap into this often-overlooked market?

1. Learn about mineral aesthetics. Visit museums and mineral shows, and consider subscribing to mineral magazines such as *Mineralogical Record*, *Rocks & Minerals*, and *Lapis*.
2. Look through your stock. High-quality rough that makes an attractive specimen could be sold to mineral collectors at your usual gem price or higher.
3. Use a different marketing channel for your minerals than you use for your gems, such as a separate website, show, booth, or display case. Or partner with a mineral dealer. Consider selling minerals in a retail venue.

HALLMARKING: A POWERFUL BENEFIT TO THE CONSUMER, RETAILER, AND INTERNATIONAL TRADE

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Since the Middle Ages, many countries have adopted assaying and hallmarking as a means of providing consumer protection and

These examples show the types of information that can be contained in a hallmark. Top left: Czechoslovakia, 1921–1929, 800 silver; top right: France, 1912–1994, 750 gold and 950 platinum minimum standards, tested by touchstone, up to 69% is gold with balance in platinum; bottom: Scotland, 1861–62, 925 sterling silver, assayed in Glasgow, duty was paid, maker's mark on left.



quality assurance with regard to the fineness of precious metal items. Today, assaying and hallmarking are universally recognized as essential to upholding such fineness standards. Just as a diamond grading report or a colored stone identification report provides the consumer with an independent confirmation of a stone's quality analysis, a hallmark is a permanent universally recognized stamp that guarantees that a precious metal item has been assayed and meets or exceeds the indicated standard of fineness.

With gold, silver, platinum, and palladium presently trading at record prices, the practice of under-karating has plagued countries without mandatory hallmarking laws. Austria, during hundreds of years of hallmarking, once had less than 1.5% of its precious metal items declared as under-karated. The country discontinued mandatory hallmarking in 2001, and by 2006 under-karating had increased to 14.9%. The government of India and their Bureau of Indian Standards, recognizing the ever persistent problem of manufactured substandard articles of precious metal, spent over 10 years implementing mandatory hallmarking, effective as of 2011.

Today with globally linked economic and social interaction, the practice of hallmarking will continue to instill consumer confidence in both the domestic and international trade of precious metal items. The Hallmark Research Institute (HRI) is dedicated to the study, education, and publication of reference materials on hallmarks of the world. HRI is a firm advocate for hallmarking and believes that, for the benefit of the consumer and for international trade acceptance, global hallmarking is a feasible goal.

A CASE STUDY IN THE PERCEPTION OF RARITY—RUBY

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Developments from the late 20th century and into the new millennium have had a profound influence on the fundamental perception of rarity in the global gem trade. The concept of rarity as it pertains to ruby, which was once regarded as the king of all gems, has been so distorted as to relegate many of these stones to costume jewelry status.

Methods for enhancing ruby have evolved dramatically during the past 25 years. At no point in history have treatments altered a gem to the extent that is routinely achieved today. The prevalence of treatments has unlocked the potential to market a vast quantity of previously unsalable natural corundum. The implications of this for the perception of rarity and the very definition of a "gem" material should be apparent.

Gemology dictates that a mineral must be *beautiful, durable, and rare* to qualify as a gem. However, current practices are navigating the international gem trade away from this standard. In recent years a proliferation of treated corundum has been marketed to consumers as "rare" and "valuable." Yet these products are

unsalable without the often substantial alteration achieved from treatment.

Historically, treated stones were not considered natural stones in commerce. This attitude appears consistent until the early- to mid-20th century, when the concept of *natural (but treated)* was promulgated among dealers. The reality is that the ability to own fine gems would not extend beyond the wealthiest members of society if not for treated gems. However, the increasing reliance on treatments has contributed to formation of a bifurcated market in which natural (unenanced) gem-quality ruby shares few if any characteristics with the vast majority of "ruby" sold as its precious namesake.

The extent to which the global market relies on treatments would suggest that it is no longer the mineral's beauty, but often instead its *potential beauty* to be achieved through treatments that joins durability and "rarity" as a defining trait.

Additional challenges regarding nomenclature have caused confusion in the ruby market. It is not uncommon to encounter a gem that is sold as "unheated" yet has some superficial enhancement (e.g., oiling) that goes undisclosed. Inconsistencies in nomenclature are also seen in the area of provenance testing. Terms such as *Classic Burma, Burma, and Burma-like* are designed to associate ordinary material with a high-value provenance. Yet it was the historic *rarity* of fine ruby from Burma that led to its recognition as the pricing benchmark by which all other origins were measured. With an abundance of corundum that can be vastly improved by treatments, what image will the term *ruby* create in the minds of consumers in the future?

ABBREVIATED JEWELRY DESCRIPTIONS—A UNIFORM STANDARD

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Shorthand notations are widely used for appraisal and auction jewelry descriptions, yet they are not employed consistently or in a systematic fashion. Standardizing these abbreviations would advance the science of gemology, and the jewelry industry at its most basic level, increasing productivity for all users.

Contract work for the U.S. Department of Justice as administered through the U.S. Marshals Service in the past five years has developed a standardized system of written abbreviations for jewelry descriptions. The system is effective in quickly and concisely communicating levels of quality between professionals, resulting in increased efficiency in appraisals, note taking, inventory, and auction cataloging. Adopting these standards throughout the gem and jewelry industry would foster improved communication within the trade, and would bridge the communication gap between jeweler and consumer.

Here is an example of an auction description of a jewelry item: RING: Lady's 14kt diamond engagement ring; 1 (ctr) rb dia, 5.68mm × 5.72mm × 3.42mm = est 0.76ct, V.Good/G/VS₂; 4 tap bag dias, 4.0mm × 2.0mm-1.5mm = est 0.40cttw, Good/G-I/VS; Size 6.5; * tdmk; 6.84 grams.

Partial listing of jewelry description abbreviations.

Karat	kt	Equals	=
Center	ctr	Estimated	est
Round Brilliant	rb	Carat	ct
Diamond	dia	Very Good (cut)	V.Good
Millimeter	mm	Carat Total Weight	cttw
By	x	Trademark	tdmk

LECTURES—AN INSPIRATIONAL WAY FOR ARTISTS TO COMMUNICATE

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Gem and jewelry artists should explore every path that can lead them to new customers, including telemarketing, email, the Internet, and social media. Another very successful approach is through lecture presentations: events where you can showcase and describe your artwork, while demonstrating your expertise. Giving a well-organized presentation that features distinctive photos, along with exhibiting some characteristic pieces for participants to examine, is an engaging form of communication. Whether it is a highly specialized trade audience at a national event, or your local gem and mineral society, arts group, or civic club, you have an audience that came to listen to you. Face-to-face personal interaction is one of the best ways to find new customers. Potential customers become engaged when they hear your personal story. They want to know when and how you got started, who influenced you, sources of inspiration, and the process of creation. These are the main questions asked time and time again. Your audience is looking for an understanding of the value of your work, an inspiration to start creating their own jewelry and cut stones, a reason to own one of your pieces, or maybe all of the above. They are looking for encouragement and knowledge.

In giving your talk:

- Share your journey, elaborate on your artwork, and disclose techniques.
- Discuss the costs behind the artwork.
- Give a virtual tour of your workshop. Show your tools.
- Describe labor-intensive lapidary and jewelry procedures.



This necklace Marine Ray, featuring a detachable pendant and pin, is composed of carved Larimar (205.0 ct), two faceted chrysoberyls (1.12 carats total) and freshwater cultured pearls, set in 18K yellow gold. Photo by A. Herman and H. Serras-Herman.

- Know the origin and properties of your gem materials.
- Feature new or rare gem materials (e.g., Larimar), and share stories about their discovery, or your personal mining adventures.
- Invite them to visit your website to look at your artwork and calendar of upcoming events for shows and lectures.
- Invite them to your next open studio, show, or exhibit.

Benefits:

- The value of your artwork will be better understood.
- Those previously unfamiliar with your work may become your new customers, while your existing clientele may see a new piece that they would like to have.
- There may be people in the audience from another group or organization who may in turn invite you to make a presentation.
- The host group, the local newspaper, or a national magazine may write an article about the event and your work.

Give an inspirational talk, and your artwork will become memorable. Connect with your lecture audiences and you will find loyal new customers.

POLISHED DIAMOND SUPPLIES FROM SECONDARY MARKET SOURCES

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The supply of polished diamonds from secondary market sources—that is, sales from consumers and estates back into the trade—has increased nearly threefold during the past five years because of two major factors: (1) record prices for gold and platinum have provided an economic incentive for consumers to sell their jewelry items for their metal value, and (2) the difficult economy of the past three years has made the sale of jewelry items necessary for many people. The path of these diamonds can be traced through a number of channels, including retail jewelers, pawn shops, special trade shows, liquidators, a brokers' network and back to the New York and Indian diamond industries. While no exact figures are available, the estimated quantity of diamonds sold through such channels in 2010 ranged between two and three million carats—an output comparable to a major diamond mine.

The potential for recovering diamonds from previously sold jewelry is vast. Surveys of the U.S. diamond jewelry industry conducted between 1976 and 1999 found that more than 400 million pieces were sold on the secondary market during that period.

RECOMMENDATIONS FOR ADVANCING THE COLOR SCIENCE OF GEMOLOGY

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A simple nomenclature change for diamond master stones, from E, F, G, and so forth to D-E, E-F, F-G, etc., along with a tightening of tolerances and the elimination of the mid-grade master, would improve the system of color grading. It would enable industry professionals to determine more precisely which color grade a diamond will receive on a grading report.

Face-up color descriptions of diamonds such as *top white*, *white*, *near white*, and *yellowish white* are more meaningful than the table-down descriptions of *colorless*, *near colorless*, and *faint yellow*. When transparent, colorless diamonds are viewed face-up, the light that is reflected appears white, just as it does when reflected from crushed ice or fallen snow.

The fancy-color diamond system rates the amount of color in a stone, rather than describing its face-up color appearance. The terms *Fancy Yellow* or *Fancy Pink* are incomplete, lacking adjectives to better define their place in color space. The *Fancy Intense Pink* grade is given to diamonds with less color saturation than comparably described colored gemstones. I propose that fancy-color diamonds be described and graded using the same system

that is used for colored gemstones.

In the real world of color, as tone is increased in certain hues, the color we perceive changes. Pink turns red, yellowish pink turns orange, and yellow turns brown. The Munsell Color-Order System, developed in 1905, accurately describes the visual color space on three axes, each scaled with equal visual steps representing hue, tone, and saturation. I recommend that the industry adopt its use.

The Verilux lamps used in the GIA DiamondLite and DiamondDock emit a significant amount of UV radiation. A very strong blue fluorescent diamond will have its true bodycolor appearance and grade improved by three to four letter grades when viewed under Verilux lamps. LED lighting is UV free. Because approximately 15% of the diamonds have fluorescent strengths great enough to be affected, I propose that two different color grades be given on a diamond grading report. One grade would be assigned while being viewed under Verilux lamps, and one while under LED lamps.

When a lab uses a faint blue fluorescent diamond master standard to determine fluorescence strength, it is inaccurate to note a stone having slightly less fluorescence as *None*. I suggest that *None* be replaced with *Negligible*.

Because fluorescence is noted on diamond grading reports for identification purposes, it is important to include a hue with the term *Faint*. I suggest that labs using *Faint* to describe fluorescence change their policies to include a hue in their description.

THE ANAHÍ AMETRINE MINE: A MODEL FOR GEMSTONE SUSTAINABILITY

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In southeastern Bolivia, close to the Brazilian border, lies the world's principal source of ametrine. Once under the control of the Bolivian military, the Anahí mine reverted to private ownership in the late 1980s. Since acquiring the mine, Ramiro Rivero has transformed the custodianship of the mine's resources, its product marketing, and environmental impact.

Anahí is managed by a group of companies, the Minerales y Metales del Oriente Group (M&M), that includes the mining camp concession and sorting facilities. In Santa Cruz de la Sierra, M&M oversees Anahí Jewelry Manufacturing, which includes factories for performing and cutting as well as jewelry design and manufacturing. M&M also administers retail outlets and franchises across Bolivia under a division known as Joyerías Anahí, SRL.

Rivero's mine-to-market approach is guided by the safety and well-being of the group's 300 employees. Working hours are regulated at the mine, where the miners receive three daily meals,

and leisure time is promoted for greater creativity and better morale. Because of the area's remoteness, telephone service is provided to keep miners in touch with families far away. In addition to a nurse and emergency medical facilities, a local airstrip is available for the rapid transport of injured or sick workers to hospitals in larger cities. Gender equality at M&M's sorting, cutting, and jewelry design plants is also evident. "I want anyone to feel comfortable coming into my office with an idea," Rivero says. "We are a family."

M&M is conscious of the mine's environmental footprint. One illustration of this is the handling of silt from the water canons used to wash the mined material. The silt is systematically separated, dried, and used for brick making or remixed with larger particulates. Also strict prohibition on hunting and fishing on the mine's property is enforced.

The socially and environmentally responsible practices implemented at Anahí serve as a model for other gem localities.



Minerales y Metales del Oriente controls the supply chain of amethyst, citrine, and ametrine from the mine to the market in a sustainable fashion. Here, a worker sorts rough ametrine crystals. Photo by R. Weldon.

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RESEARCH ON GEM FELDSPAR FROM THE SHIGATSE REGION OF TIBET

Ahmadjan Abduriyim, Shane F. McClure, George R. Rossman, Thanong Leelawatanasuk, Richard W. Hughes, Brendan M. Laurs, Ren Lu, Flavie Isatelle, Kenneth Scarratt, Emily V. Dubinsky, Troy R. Douthit, and John L. Emmett

The existence of a natural red andesine deposit in China/Tibet has been the subject of controversy since 2006. In late September 2010, an international group traveled to the Shigatse region of Tibet and visited two reported andesine occurrences, at Zha Lin village and the Yu Lin Gu alluvial fan. These sites are located ~3 km from the previously investigated Bainang andesine mining area near Nai Sa village. The Zha Lin deposit appeared genuine, but the group could not confirm the authenticity of the Yu Lin Gu occurrence, and no primary andesine-bearing source rocks were found in either area. Some of the samples had glassy surface residues that are difficult to explain naturally, while initial argon isotopic measurements of a few Zha Lin and Yu Lin Gu andesines (without glassy residues) showed that they had not been heated. Laboratory studies of the Tibetan samples—and a comparison to known-treated red andesine from Inner Mongolia—showed that it may be possible to separate these feldspars using a combination of several advanced destructive techniques, but this methodology is not practical for gem testing laboratories. More detailed investigations will be needed to establish feasible identification criteria for natural-color andesine from Tibet.

Copper-bearing red to green plagioclase feldspar of gem quality has been known from Oregon for decades (e.g., Johnston et al., 1991). In 2002, a new gem plagioclase appeared on the market, allegedly from the Democratic Republic of the Congo (Fritsch, 2002; Krzemnicki, 2004; here referred to as the Congo), and similar material appeared in 2005 that was represented as being from Tibet (see, e.g., figure 1 and Laurs, 2005). Chemical analysis of red feldspars reportedly from Tibet (an autonomous region of China) and the Congo showed that they fall near the border of the andesine-labradorite compositional range (Abduriyim, 2009b; Rossman, 2011); for simplicity, this material will be referred to as andesine in this article.

Reports published in 2008 showed evidence that

copper was being diffused into andesine in China and Thailand by a multi-step heating process (Furuya, 2008; Milisenda et al., 2008). While this was apparently being performed on an experimental basis in Thailand, commercial treatment was reportedly taking place in China by a professor in Xi'an (Lang, 2002). The starting material was alleged to be pale yellow andesine from Guyang County, Inner Mongolia, China. Suspicions about the authenticity of the "Chinese red feldspar" on the market circulated on the Internet and elsewhere (e.g., Furuya, 2008; James, 2008).

To address whether natural red andesine occurs in Tibet, in 2008 one of the authors (AA) and five gem dealers and a gemologist visited an alleged deposit called Bainang (or Bai Lang), located near Nai Sa village ~55 km southeast of Shigatse (or Xigazê; see figure 2; Abduriyim, 2008, 2009a,b). The visit was organized by Chinese miner Li Tong (Tibet Andesine, Shenzhen, China). Author AA also visited two deposits of pale yellow andesine in Inner

See end of article for About the Authors and Acknowledgments.

GEMS & GEMOLOGY, Vol. 47, No. 2, pp. 167–180.

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Figure 1. These andesines (6.71–15.51 ct) were represented as untreated (natural color) stones from Tibet. Courtesy of Do Win Development Co. Ltd.; photo by Robert Weldon.



Mongolia (Shui Quan and Hai Bou Zi, both in Guyang County), and samples were collected at each locality. In addition, he attempted to contact the Chinese trader in Xi'an, who was unwilling to meet with him.

The internal features and chemical composition of the Tibetan samples collected on the 2008 expedition were found to closely resemble the allegedly copper-diffused Inner Mongolian red andesine on the market, to the degree that doubt was cast on the natural origin of the Tibetan stones (Hughes, 2010; Rossman, 2011).

In an effort to resolve the controversy, other field trips to Tibet were carried out in 2009 by

GemResearch Swisslab (GRS, Lucerne, Switzerland) and in 2010 by China's National Gemstone Testing Center (NGTC, Beijing). Dr. Adolf Peretti from GRS was taken by Li Tong to a Tibetan deposit located hundreds of kilometers away from the site of AA's 2008 Tibet trip (again, see figure 2), but Peretti concluded the occurrence was fake (Fontaine et al., 2010). On two expeditions in May and August 2010, teams from NGTC collected andesine samples from a reported deposit near Zha Lin village and at the Nai Sa-Bainang mine. They believed that these sites were probably "salted," but that the question could only be truly answered with a full geologic survey of the area (Wang et al., 2011).



Figure 2. The reported andesine mines visited by Abduriyim's 2010 expedition are located in south-central Tibet, ~55 km from Shigatse. Also shown is another reported andesine occurrence in Tibet (Gyaca) that Fontaine et al. (2010) determined was fake. The inset shows the locations of the reported Zha Lin, Yu Lin Gu, and Nai Sa-Bainang andesine localities in Tibet.

In late September 2010, another party visited Tibet that included authors AA, BML, RWH, TL, FI, and Young Sze Man of *Jewellery News Asia*. Accompanying them were Christina Iu (M. P. Gem Corp., Yamanashi, Japan), Li Tong and his wife, and He Qung (an employee of Mr. Tong's). They studied the reported andesine occurrence at Zha Lin village, as well as an additional locality called Yu Lin Gu (Abduriyim and Laurs, 2010; Abduriyim et al., 2010;

GIA website (www.gia.edu/research-resources/news-from-research/index.html). Although the andesine controversy is still not resolved, it is hoped that this article will provide a foundation for others who wish to pursue further studies of this material.

NEED TO KNOW

- At Zha Lin and Yu Lin Gu in southern Tibet, andesine pebbles are hosted by alluvial sediments, as at the nearby Nai Sa–Bainang occurrence.
- Samples from all three localities showed overlapping gemological and chemical properties, except for traces of Ag in Yu Lin Gu andesine.
- Some of the samples had glassy surface residues, while initial argon isotopic measurements of pieces from Zha Lin and Yu Lin Gu (without glassy residues) showed no evidence of significant heating.
- No reliable and practical methodology was found for separating these feldspars from known-treated red andesine from Inner Mongolia.

Hughes, 2010; Leelawatanasuk, 2010). These areas are located ~3 km from the Nai Sa–Bainang mining area that AA visited in 2008. Due to the objection of a local monk who controls access to the land in this area, the party was unable to visit the Bainang mine. According to villagers interviewed by the expedition, the orange-red stones have been known in this region of Tibet for several decades or longer.

This article reviews the geologic field information gathered by the expedition group and briefly summarizes results of laboratory work on the samples they collected, including their gemological properties, surface features, chemical and isotopic composition, and structural order as revealed by powder X-ray diffraction. In addition, this study gives observations of “matrix” specimens that were supplied through Li Tong, and also reports some initial experiments that investigated the diffusion of silver into andesine (since this element was detected in samples from the Yu Lin Gu occurrence). Due to space limitations, only brief excerpts of this research could be published here; full reports are available on the

LOCATION AND ACCESS

With the exception of the occurrence visited by Dr. Peretti, the reported andesine deposits are located in Bainang County, ~55 km southeast of the region's second largest city, Shigatse (or Xigazê), in southern Tibet (figure 2 and table 1). All three localities (Nai Sa–Bainang, Zha Lin, and Yu Lin Gu) are situated within 2–3 km of one another. They are located ~8 km southeast of Bainang town, near the villages of Zha Lin (Zha Lin and Yu Lin Gu localities) and Nai Sa (Bainang mine).

From the capital city of Lhasa, it takes more than five hours to drive ~300 km to Shigatse on a paved road that crosses two passes at 4,900 and 5,088 m. From Shigatse, it takes another 1–2 hours to drive to the mining area on mostly paved roads. Foreigners are forbidden from visiting this area without authorization from both the Chinese government and local authorities.

GEOLOGIC SETTING

The andesine is hosted by alluvial sediments weathered from sedimentary formations consisting mainly of shale and clay-rich sandstone. These were described as Tertiary on a geologic map published by the Chinese government (“Qin Zang Gao Yuan . . .,” 2005), while Guilmette (2008) indicated that the sedimentary formations in this area are much older (Late Triassic). Mechanical weathering of these rocks created alluvial fans and stream-deposited gravels that locally contain pebbles of the andesine. No original host rocks for Tibetan andesine were found during any of the field studies mentioned

TABLE 1. Reported andesine deposits in Tibet.

Site	Coordinates
Bainang (South)	29°02.57'N, 89°22.17'E; 4,072 m (13,360 ft.) ^a
Bainang (North)	29°02.71'N, 89°22.18'E; 4,049 m (13,285 ft.) ^a
Zha Lin	29°03.95'N, 89°20.88'E; 3,929 m (12,891 ft.)
Yu Lin Gu	29°03.08'N, 89°20.76'E; 4,102 m (13,460 ft.)
Gyaca (Jia Cha) County, Shan Nan area ^b	29°08.07'N, 92°35.95'E; 3,400 m (11,155 ft.)

^a Coordinates for the Bainang localities are from Wang (2011).

^b Visited by GemResearch SwissLab in 2009, but determined to be “salted.”



Figure 3. At Zha Lin, andesine was said to be mined from shallow pits such as those shown here. Excavations in this area by Abduriyim's 2010 Tibet expedition revealed andesine within silty sediments (inset). Photos by B. M. Laurs.

above, and the expected rock types (i.e., lavas of basaltic composition) are not shown on geologic maps of the area. Therefore, if such rocks previously existed in the area, they must have been tectonically displaced and/or have weathered away.

The following geologic descriptions are summarized from observations made during Abduriyim's 2010 expedition. At Zha Lin, andesine was found in gray silty sediments of an alluvial plain (figure 3). Miner Li Tong informed the team that local people recovered ~2 tonnes of andesine using simple hand-mining methods; shallow pits were visible over an area measuring approximately 200 × 100 m. The authors randomly selected several areas within and upstream from the former mining area and dug five pits up to 1.2 m deep. They found andesine in nearly all the pits, including those dug ~30 m upstream from the mining area under slow-growing thorn bushes at depths down to 30 cm (about 12 inches; figure 4). The discovery of andesine within pits dug in random, previously unexplored areas near the Zha Lin mining area is consistent with what we would expect for a genuine Tibetan andesine deposit.

The Yu Lin Gu occurrence (figure 5) is located on an alluvial fan 2 km upstream and to the southwest of Zha Lin. Andesine was locally concentrated in patches on the surface of the fan within gravel and rock fragments (figure 5, inset), and also in an intermittent creek on the fan. Local people reportedly picked up ~200 kg andesine from the surface; there was no evidence of any excavations. The team dug several pits, but recovered andesine only at the surface (or rarely within a few centimeters of the sur-

face in a thin layer of loose silty sand). Because expedition members did not find samples at depth, they could not verify the authenticity of the deposit.

MATERIALS AND METHODS

Four matrix samples of andesine (as well as 12 pieces with small amounts of matrix attached) were examined by authors SFM and KS at GIA in Carlsbad and Bangkok, respectively, using a gemological microscope, Raman spectroscopy, and laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS). Additional matrix samples were studied at the California Institute of Technology using attenuated total reflection infrared spectroscopy. All the matrix samples were obtained indirectly through miner Li Tong, and stated to be from Tibet.

Figure 4. This 30-cm-deep pit was dug by Abduriyim's 2010 Tibet expedition under a thorn bush selected at a random location above the Zha Lin mining area. Several pieces of andesine were recovered from this pit. Photo by B. M. Laurs.



Unless otherwise indicated, all the additional samples described in this article were obtained on Abduriyim's 2010 expedition. These were personally collected by expedition members (for samples from Zha Lin and Yu Lin Gu, e.g., figure 6 [left and center]) or purchased by them in Nai Sa village (for samples from the Bainang mine area, which had reportedly been collected there by local people since 2007; see figure 6, right). In addition, in Guangzhou the group obtained a parcel of pale yellow andesine reportedly mined in Inner Mongolia, as well as two lots of red andesine that were reportedly copper-diffused in China using Inner Mongolian pale yellow andesine as starting material (figure 7)—either in Xi'an in 2004–2005 or in Shenzhen in 2007–2008. Hereafter, these Cu-diffused samples will be referred to as “known-treated” andesine. Operating conditions for the electron microprobe, LA-ICP-MS, and X-ray diffraction analyses described below are reported in the respective full articles on the GIA website.

The gemological properties (RI, SG, UV fluorescence, Chelsea filter reaction, spectroscopy observations, and microscopic characteristics) of 198 pieces of reddish orange to orange-red andesine from Zha Lin and Yu Lin Gu were collected by author AA using standard instrumentation. From these, 95 were polished with two parallel windows, and were cleaned with acetone and aqua regia in an ultrasonic bath to remove surface contamination. In addition, 50 known-treated red andesine samples (from both Xi'an and Shenzhen) were characterized.

Author TL conducted a preliminary study of surface residues on four additional red Tibetan samples (one from Yu Lin Gu and three from Nai Sa–Bainang) and two red pieces of the known-treated andesine using a scanning electron microscope (SEM) at the Scientific and Technological Research Equipment



Figure 5. The Yu Lin Gu andesine occurrence consists of an alluvial fan where andesine has been found locally scattered on the surface and in an intermittent creek (photo by B. M. Laurus). The inset shows a red andesine pebble as it was found on the surface of the alluvium (photo by A. Abduriyim).

Center, Chulalongkorn University, Bangkok, using a JEOL JSM-5800LV instrument equipped with an energy-dispersive spectrometer; it was capable of 200–10,000× magnification.

Quantitative chemical analysis using a JEOL JXA-8500 electron microprobe was carried out by author AA at NIMS (Tsukuba, Japan) on polished surfaces of eight orange-red and red samples (two each obtained at Zha Lin and Yu Lin Gu during the 2010 expedition, and two each of the known-treated stones from Xi'an and Shenzhen). Five spots were analyzed on each sample.

LA-ICP-MS trace-element data were obtained by author AA from 80 orange-red to red Tibetan samples (20 from Zha Lin and 40 from Yu Lin Gu obtained in 2010, and 20 from Abduriyim's 2008 expedition to Nai Sa–Bainang), 45 known-treated red samples (22 from Xi'an and 23 from Shenzhen), and 12 pale yel-

Figure 6. Some of the andesine samples obtained by Abduriyim's 2010 expedition are shown here. From left to right, the samples are from Zha Lin (0.10–1.14 g, personally collected), Yu Lin Gu (0.25–1.55 g, personally collected), and Nai Sa–Bainang (0.37–2.92 g, purchased in Nai Sa village). Photos by Robert Weldon.



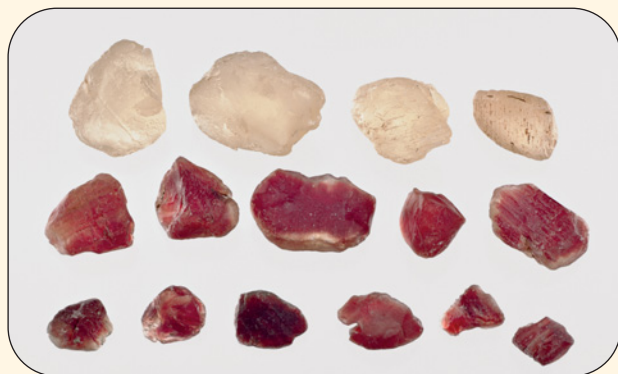


Figure 7. These samples, which were obtained in Guangzhou by Abduriyim's 2010 expedition, consist of pale yellow Inner Mongolian andesine (top row, 5.21–15.36 g) and red andesine that was reportedly treated in China using the Inner Mongolian starting material. The samples in the middle row were said to have been treated in Xi'an in 2004–2005, and those in the bottom row were reportedly treated in Shenzhen in 2007–2008. Photo by Robert Weldon.

low pieces from Inner Mongolia. The instrumentation consisted of a New Wave Research UP266 laser ablation system attached to an Agilent 7500a series ICP-MS at the GEMOC Key Centre, Macquarie University, Sydney, Australia.

Author AA also arranged for powder X-ray diffraction measurements at the Australian Museum on 42 samples to investigate whether the feldspar's lattice (unit cell) parameters were indicative of treatment. These consisted of 20 pieces of orange-red and red andesine from Tibet (5 from Zha Lin, 5 from Yu Lin Gu, and 10 from Nai Sa-Bainang), 10 red known-treated stones (five each from Xi'an and Shenzhen), and 12 pale yellow samples from Inner Mongolia. Data were collected with a Shimadzu LabX XRD-6000 X-ray diffractometer, and the lattice parameters were calculated by the least-squares method using CELLCalc software, with $\Delta 2\theta = 2\theta_{\bar{1}\bar{3}1} - 2\theta_{131}$ to determine structural states based on measurement of the spacing between the $(\bar{1}\bar{3}1)$ and (131) peaks of the powder X-ray diffraction pattern (Ribbe, 1972). To test whether the $\Delta 2\theta$ parameters were changed by heating, we selected two pale yellow Inner Mongolian samples for copper diffusion experiments. Each sample was cut into two pieces. Half of one sample (INMG-DF-001a) was buried in ZrO_2 powder mixed with 2–3% copper powder and diffused at 1160°C for 50 hours, and half of the other stone (INMG-DF-002a) was packed into Al_2O_3 powder mixed with 2–3% copper powder and heated at 1000°C for 24 hours. The remaining halves were retained as control samples.

Argon isotope measurements were conducted in the Farley lab at Caltech on nine samples (one red piece from Abduriyim's 2008 expedition, six red pieces obtained during his 2010 Tibet trip, one red "Chinese" sample donated by Andegem, and one piece of yellow Inner Mongolian andesine). The samples were prepared and analyzed following the procedures described in Rossman (2011), except that each sample was wrapped in aluminum foil and placed under high vacuum overnight, and then was completely melted in a tantalum furnace (rather than being heated by a laser) for argon extraction.

Traces of silver have been detected in andesine collected from Yu Lin Gu (A. Abduriyim, unpublished data), so a set of diffusion experiments were conducted by authors RL, EVD, TRD, and JLE at Crystal Chemistry to better understand silver incorporation in plagioclase. Two sets (10 pieces each) of pale yellow andesine from Inner Mongolia were sliced into wafers ~3–3.5 mm thick. They contained various amounts of snowflake-like inclusions, fine particulate clouds, and some growth tubes. The samples were packed in ZrO_2 powder doped with 1% metallic silver. One set (cc1032-2) was diffusion treated at 1170°C for 31 hours, and the other set (cc1032-3) was treated at the same temperature for 180 hours. The temperature was chosen to be near 90% of the solidus temperature of the material to facilitate efficient diffusion. One untreated sample and three samples from each treatment condition were sliced in half and the cut edges were polished for chemical analysis by LA-ICP-MS.

RESULTS AND DISCUSSION

Matrix Rock Observations. All the matrix material had a similar appearance, consisting of a light gray porous substance containing tube-shaped structures (figure 8, left). The matrix was found to be calcium carbonate (mostly calcite) that apparently formed by secondary precipitation (i.e., caliche). Such a matrix has not previously been reported for andesine.

Closer inspection of the specimens revealed additional features that were hard to explain. In many pieces, junctions between the andesine and matrix contained a transparent to translucent material that resembled liquid but was not. It "wetted" the surrounding matrix, filling in pores and making them shiny (figure 8, center), often forming a meniscus where the feldspar came in contact with the matrix. LA-ICP-MS chemical analysis of this contact material showed mostly aluminum with some silicon and calcium, as well as numerous trace elements. No



Figure 8. The matrix samples contained rounded pieces of andesine embedded in porous carbonate rock that had the appearance of caliche (e.g., left image). The junction of the andesine and the matrix, as well as the surrounding area, contained a material that made the porosity of the matrix look wet and shiny (center, field of view 4.0 mm). One specimen contained transparent blue fibers that were flexible (right, field of view 1.0 mm) and partially melted during Raman analysis, which produced spectra similar to nylon. Photos by K. Scarratt (left) and S. F. McClure.

spectral match—or polymers—were found using Raman spectroscopy.

Some of the specimens had fibers embedded in the matrix and in the contact material. In at least one specimen, the fibers were blue and flexible (figure 8, right). Raman analysis of the most accessible fiber proved difficult because it melted when exposed to the laser, even after the power level and laser frequency were changed. The best match for the (weak) Raman signal was nylon. We concluded that the fiber was man-made and could not have occurred naturally in the specimen. Further examination also revealed parts of insects stuck in the matrix.

One large matrix specimen was broken apart with a hammer, but no andesine was found inside. The two pieces of andesine originally visible on the surface of the specimen were both broken out of the matrix, and one of them had a flat cleavage surface that left a well-preserved imprint in the contact material where it was attached to the matrix. This area had a fine texture that was somewhat glassy, and it was completely unlike the surrounding matrix. It did not bear any resemblance to a natural material.

Analysis of small fragments (<250 μm) of the contact material by attenuated total reflection IR spectroscopy showed calcite plus some organic material, as indicated by C-H absorptions near 2900 cm^{-1} . In contrast, spectra of the matrix away from the andesine showed dominantly calcite. While not proof of an assemblage, this is consistent with the presence of an organic binder used to attach the andesine to the matrix.

Our observations suggest that the matrix specimens were manufactured. In addition, no specimens of this kind were seen by team members who visited the reported mine sites in Tibet.

Gemological Observations. The andesine samples collected from Zha Lin and Yu Lin Gu were generally visually indistinguishable from one another and from those obtained in Nai Sa village that were represented as being from the Bainang mining area (with exceptions indicated below). Most were transparent to translucent, but their overall gem quality was not high (again, see figure 6). In fact, very few of the samples would be expected to yield high commercial-quality cut gemstones. Most of the pieces were under a centimeter and the largest reached ~2 cm. Most were pale orangy red or red, with some rare pure red samples. Compared to andesine from the Nai Sa–Bainang area, the Zha Lin and Yu Lin Gu samples generally were a weaker red (again, see figure 6). Some stones showed blue-green or red zones or patches (e.g., figure 9), and any surface-reaching fractures were surrounded by a narrow colorless zone. In addition, a few of the Yu Lin Gu samples showed a distinct yellow color zone near their surface. Most samples also had a narrow colorless rim along their surface, and some stones showed concentric color zoning with green-blue and red bands (see, e.g., figure 14 in Rossman, 2011). All samples were rounded, with a smooth waterworn appearance and generally elongated shapes. A few andesines had broken cleavage surfaces, embayed areas that appeared to have been created by chemical etching, or areas with a melted glassy surface (see further description below). Etch features are common in known-natural feldspars from other sources such as Oregon, but to our knowledge melted glassy surfaces are not.

The gemological properties are summarized in table 2. RI and SG values for all samples fell in the range of andesine. The samples fluoresced weak chalky orange to long-wave UV radiation, and were dark red or inert under short-wave UV. They retained

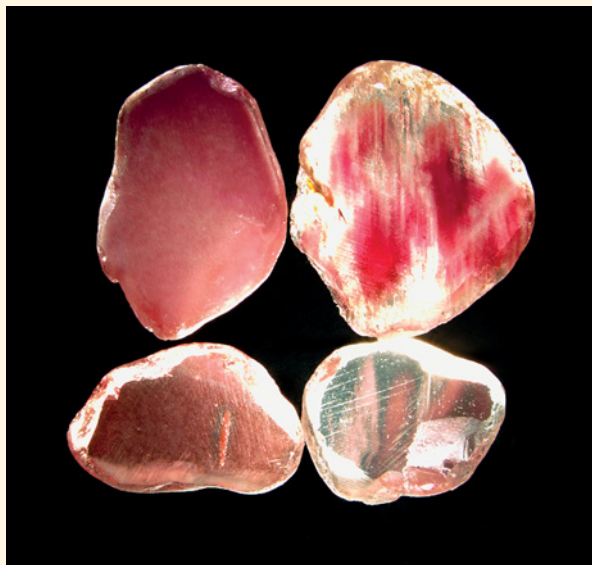


Figure 9. These Tibetan andesine samples (0.20–1.01 g, from Yu Lin Gu) show various uneven blue-green or red zones. Surface-reaching fractures are surrounded by narrow colorless areas. Photo by A. Abduriyim.

their red appearance under a Chelsea filter. Some red stones appeared green in diffused transmitted light.

Microscopic examination revealed that most of the Zha Lin and Yu Lin Gu samples contained prominent twin lamellae parallel to {010}, turbid milky clouds and particles between the twin lamellae (figure 10, left), parallel lath-like hollow channels, pipe-like structures, irregular dislocations (figure 10, center), and fissures. A few stones also contained partially healed fractures that had no surface expression in reflected light. A very few samples contained native copper grains or platelets, which produced reddish orange schiller after polishing (figure 10, right). Similar copper platelets are known in Oregon labradorite, but those platelets tend to be much larger. No platelets were seen in any of the

TABLE 2. Gemological properties of rough andesine obtained in Tibet in 2010.

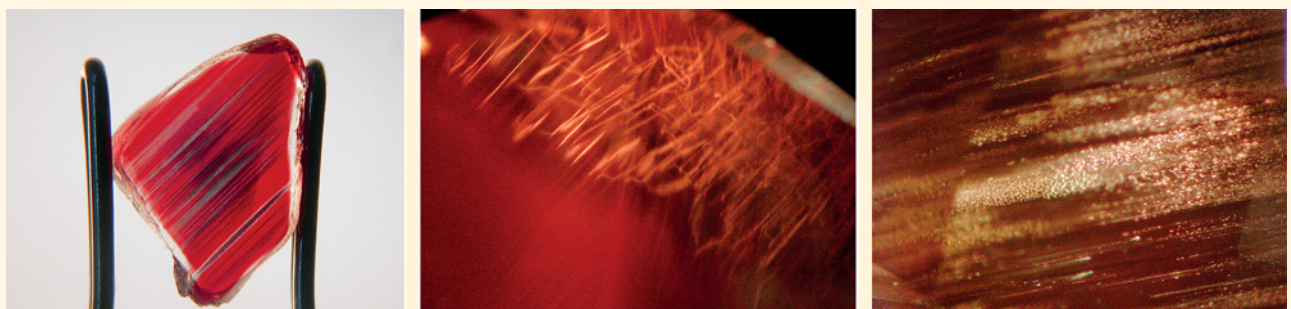
Color	Reddish orange, orange-red, and deep red, sometimes with a colorless rim and/or uneven green or bluish green zones, patches, or stripes.
Diaphaneity	Transparent to translucent
Appearance	Smooth rounded faces, some cleavage surfaces, surface etching, melted glassy surface
RI ^a	$\alpha = 1.550\text{--}1.552$, $\beta = 1.555\text{--}1.557$, $\gamma = 1.560\text{--}1.561$
Birefringence	0.009–0.010
Optic sign	Biaxial positive
SG	2.67–2.72
Pleochroism	Weak (red-green)
UV fluorescence	
Long-wave	Weak chalky orange
Short-wave	Dark red or inert
Chelsea filter	Red (for red samples)
Spectroscope	Broad absorption at 560 nm in red stones and a very weak band at 630 nm in green color zones.
Internal characteristics	Color zoning, twin lamellae, turbid milky clouds and particles, lath-like hollow channels, pipe-like growth tubes, irregular dislocations, fractures, uncommon tiny native copper grains or platelets

^a Measured on polished surface.

known-treated samples.

The known-treated samples contained pipe and tube-like structures, discoid fractures, a recrystallized white residue filling the lath-like hollow channels, and cloud-like inclusions. Overall these internal features resembled those seen in the Tibetan andesines. However, distinct concentric color fluctuations from the rim to the core were present in some of the known-treated stones (e.g., figure 11). These layer-by-layer color zones appeared more distinct than in the Tibetan samples examined.

Figure 10. Some internal features noted in the Tibetan andesine included turbid milky clouds and particles between twin lamellae (left), irregular dislocations (center), and rare schiller from the presence of native copper inclusions (right). Photomicrographs by F. Isatelle (left, magnified 10 \times) and A. Abduriyim (center and right, magnified 15–20 \times).



Surface Residue Features. Microscopic observation of the samples from all three reported Tibetan localities, as well as the known-treated andesines, revealed unusual glassy surface residues in the fractures, cavities, and depressions of some specimens, as reported previously in red andesine from Tibet or “China” (e.g., Abduriyim, 2009b; Lan et al., 2009; Rossman, 2011). However, many of the samples studied (~80–85%), whether Tibetan or known treated, did not show any residues, and residues were not present on any of the pale yellow andesine from Inner Mongolia. Of the six specimens examined by author SFM that were dug from two random holes above the main mining area in Zha Lin, three had these glassy residues in depressions or cavities.

The residues (e.g., figure 12) ranged from opaque to transparent and were colorless/white, yellow, orange, brown, or black. Microscopic examination of these residues typically showed characteristics of a viscous liquid that filled low areas and then solidified: a meniscus against the feldspar, columns of this material bridging gaps in the feldspar (e.g., figure 12, right), and gas bubbles. Dendritic formations of a metallic material were sometimes visible in the residues (for more on these, see the SEM study below).

On both the Tibetan and known-treated stones, the glassy residue material sometimes cemented small fragments of feldspar to the surface of the andesine, as documented previously (Rossman, 2011). Also seen were small fragments of quartz attached to the surface with a material identified by Raman analysis as amorphous silica.

Most of the Raman spectra we acquired on the residues did not match anything in our database. On a few samples, particularly in some dark areas, we obtained a good match with amorphous carbon. The chemistry of these residues was consistent between all of the Tibetan and known-treated samples that were analyzed. In agreement with the findings of Rossman

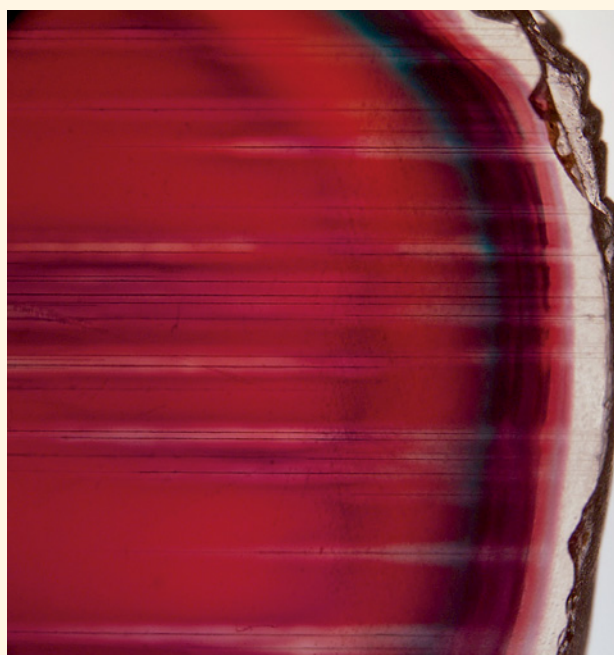


Figure 11. This known-treated andesine shows concentric color fluctuations. Photomicrograph by A. Abduriyim; magnified 22 \times .

(2011), compared to the host andesine, all the residues had relatively high levels of potassium and copper with trace amounts of numerous other elements.

At present, we do not know the origin of these residues or why there is quartz and feldspar fused to the surface of these stones.

SEM Study of Surface Features. SEM observations of red andesine samples from Yu Lin Gu and the Nai Sa-Bainang area showed percussion marks on their surfaces (figure 13, left) that appeared consistent with sedimentary transport. Whitish residues in some depressions and fractures proved to be crystalline materials containing silicon as their major constituent (probably microcrystalline silica or fine-grained quartz; figure 13, center). Some of these Si-rich patches on red andesine from Nai Sa-Bainang



Figure 12. Channels on these andesines are filled with a transparent yellow-brown glassy material (left, known-treated stone, image width 2.9 mm) or an opaque yellow substance partially bridging the gap in the specimen (right, from Zha Lin, image width 1.75 mm). Photomicrographs by S. F. McClure.

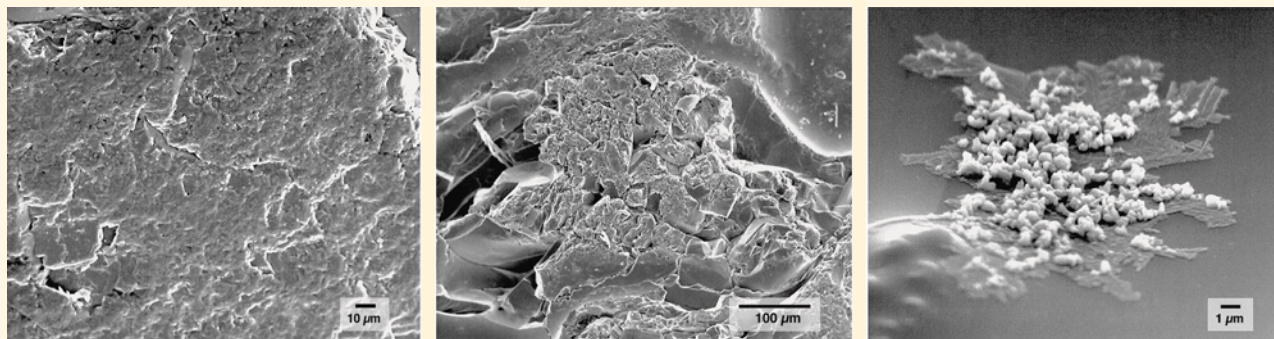


Figure 13. These SEM images of andesine surfaces show percussion marks (left) and a cluster of microcrystalline Si-rich material (center) on samples from Yu Lin Gu. The SEM image on the right of a sample from Nai Sa–Bainang shows dendritic copper growths with copper microclusters on top of a crystalline silica-rich material (right).

hosted tiny dendritic copper growths partially covered with copper-rich microclusters (figure 13, right).

SEM imaging of both of the known-treated andesines revealed mainly glassy surfaces and residues from prolonged treatment with a flux. An Al-rich compound was also observed (figure 14, left). No percussion marks were observed on these samples, but numerous copper-rich microclusters were seen on areas of silica-rich glassy residues (figure 14, right).

Chemical Composition. Microprobe analysis of two andesine samples from Zha Lin yielded a composition of $Ab_{46-47}:An_{49-50}:Or_{3.5-3.8}$ (expressed as mol.% albite:anorthite:orthoclase). They plotted in the andesine field, near the border with labradorite. Two samples from Yu Lin Gu showed a similar range of major elements but with more varying anorthite contents (An_{51-58}), which placed them in the labradorite field. With the exception of the An_{58} sample, these data overlap the compositions given by Rossman (2011) for samples from Tibet and “China.” A similar composition was documented in the Nai Sa–Bainang andesine studied by Abduriyim (2009b). Microprobe analyses of four known-treated samples gave compo-

sitions of $Ab_{46-49}:An_{47-50}:Or_{2.8-3.2}$, placing them in the andesine field at/near the border with labradorite, indistinguishable from the Tibetan samples. The Zha Lin and Yu Lin Gu andesine contained overlapping copper contents (0.04–0.15 wt.% CuO), similar to the range in the known-treated samples (0.04–0.11 wt.% CuO).

LA-ICP-MS analyses of samples from all three Tibetan localities showed a similar range of Li, B, Mg, P, K, Sc, Ti, V, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, Rb, Sr, Y, Zr, Ba, and Pb, as well as the rare-earth elements La, Ce, Pr, Nd, and Eu. Copper ranged from 270 to 1200 ppmw, and tended to be higher in stones with a redder color. Li contents showed corresponding increases with Cu, while Ni concentrations were higher at the surface than the interior.

Traces of silver were recorded only in samples from Yu Lin Gu, ranging from 35 to 2900 ppmw. The concentration of Ag at the outer edge of the samples, where a colorless rim was visible, was much higher than the average inside the stones. Also, the amount of Ag appeared to diminish toward the center of the stones. In contrast, the distribution of Cu and other trace elements throughout the sam-

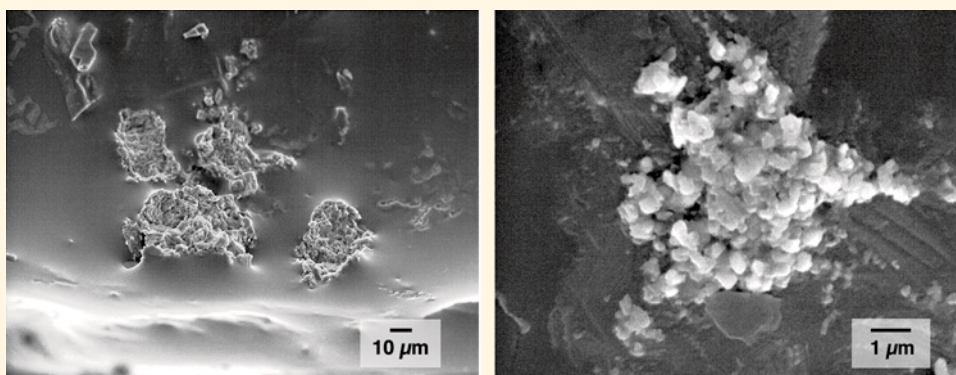


Figure 14. These SEM images of known-treated andesine samples show an Al-rich compound (left) and dendritic copper growths with copper microclusters on top of silica-rich glassy residue (right).

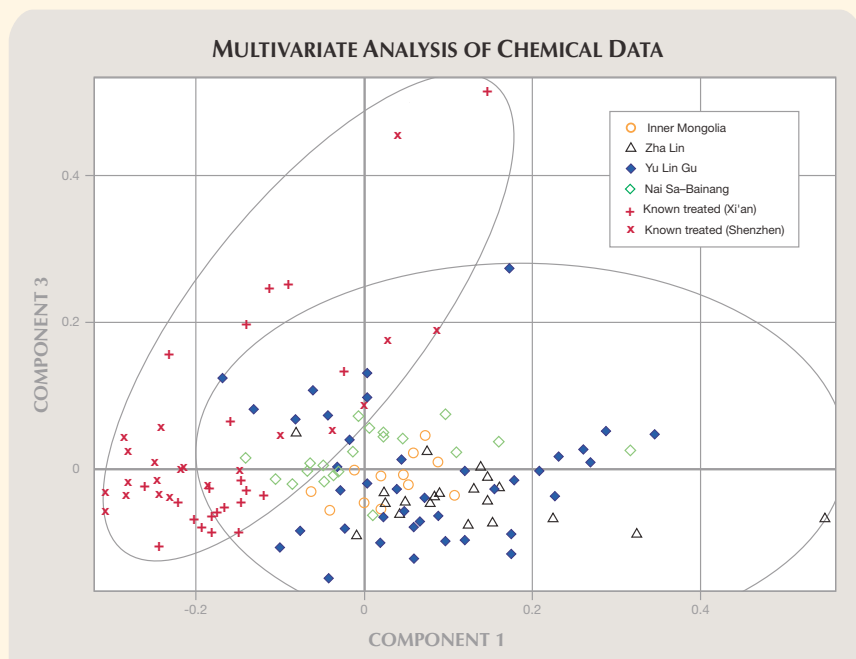


Figure 15. Trace-element data of the Tibetan/Inner Mongolian andesines and known-treated samples were processed by multivariate statistical analysis into this principal component diagram. Ten isotopes (^{39}K , ^{49}Ti , ^{57}Fe , ^{69}Ga , ^{88}Sr , ^{107}Ag , ^{137}Ba , ^{139}La , ^{140}Ce , and ^{208}Pb) were categorized into two parameters as component 1 and component 3. There is ~30% overlap between the two groups.

ples did not show any specific trends. Some stones from Zha Lin showed a very low amount of Ag at the surface (~0.12–0.26 ppm by weight) but none in their interior. Ag was not detected in any of the other stones.

The known-treated samples showed trace-element contents similar to those of the Tibetan stones, but the Cu content decreased from the rim toward the core in most of the samples. Barium contents were slightly lower (99–142 ppmw) than in the Tibetan andesine (123–166 ppmw).

Multivariate statistical analysis of the trace-element data yielded the principal component diagram in figure 15. Data are shown for the 80 samples from the three reported Tibetan localities and the 12 pale yellow samples from Inner Mongolia. The red symbols indicate the 45 known-treated samples. Although there was ~30% overlap between the two groups, the known-treated samples tended to have lower values for the component 1 parameter.

Powder X-ray Diffraction. Using the parameter of $\Delta 2\theta = 2\theta_{131} - 2\theta_{131'}$, combined with anorthite content, we can determine the Al/Si distribution among the four tetrahedral sites in the plagioclase structure (Ribbe, 1972). The diffraction data for five Zha Lin andesines gave values of $\Delta 2\theta = 1.9554^\circ - 1.9724^\circ$, while five samples from Yu Lin Gu yielded $\Delta 2\theta = 1.9572^\circ - 1.9700^\circ$ and 10 from Nai Sa-Bainang were calculated as $\Delta 2\theta = 1.9539^\circ - 1.9668^\circ$ (figure 16). Of the known-treated samples, five from Xi'an were in the range $\Delta 2\theta = 1.9574^\circ - 1.9886^\circ$ and five from

Shenzhen gave $\Delta 2\theta = 1.9720^\circ - 2.0047^\circ$. The tendency for the known copper-diffused samples to have a higher parameter is reflected by the degree of Al/Si disorder at the tetrahedral site. The temperature at which this disorder formed is probably higher than 800–900°C. The 12 pale yellow samples of Inner Mongolian andesine showed a significantly lower parameter of $\Delta 2\theta = 1.9161^\circ - 1.9506^\circ$ compared to the Tibetan and known-treated samples.

Our copper diffusion experiments confirmed that the $\Delta 2\theta$ parameter can be changed significantly by high-temperature heating. Both diffused samples showed red and green colors, and the parameters changed from $\Delta 2\theta = 1.9264^\circ$ to 1.9764° , and from $\Delta 2\theta = 1.9506^\circ$ to 1.9811° . The high temperatures associated with laboratory diffusion of Cu into plagioclase are reflected in the increased disorder measured by powder X-ray diffraction.

Argon Isotopes. Rossman (2011) reported that argon isotopic analysis of red andesine samples collected by Abduriyim's 2008 expedition to the Nai Sa-Bainang mine gave a much lower $^{40}\text{Ar}/^{36}\text{Ar}$ ratio than untreated pale yellow andesine from Inner Mongolia. These observations led to the suspicion that those Tibetan samples had been treated by high-temperature copper diffusion, despite the conclusions of Abduriyim (2009a,b), who investigated the Bainang mine, that the deposit was authentic.

The results of argon isotopic measurements of andesines obtained on Abduriyim's 2010 expedition, and of other samples for comparison, are

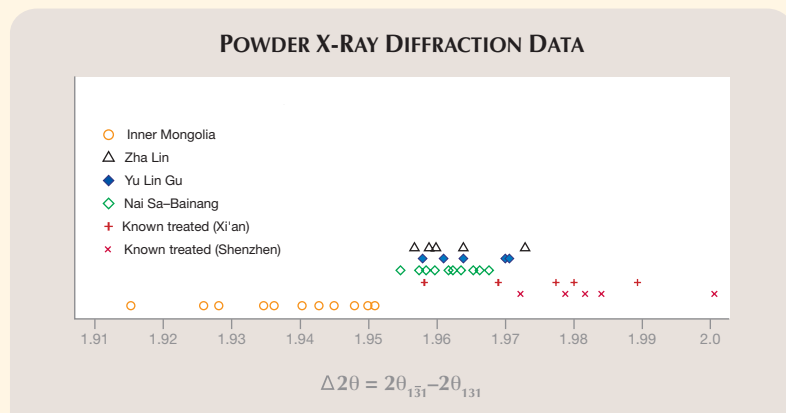


Figure 16. In this diagram, the $\Delta 2\theta$ values (calculated using the parameter of $\Delta 2\theta = 2\theta_{131} - 2\theta_{131}$) obtained from powder X-ray diffraction data show some overlap between Tibetan andesine and known-treated samples. The untreated Inner Mongolian andesine samples have the lowest $\Delta 2\theta$ values.

shown in table 3 and figure 17. None of the samples tested for argon isotopes showed evidence of the glassy surface residues mentioned above. The pale yellow Inner Mongolian rough had a high $^{40}\text{Ar}/^{36}\text{Ar}$ ratio, comparable to the results obtained in 2008. In fact, it contained so much ^{40}Ar that it saturated the detection system. However, a rough red andesine from Andegem showed a low ratio, consistent with author GRR's previous isotopic measurements from the same sample and the conclusion that such material was diffusion treated at high temperatures. A rough red sample purchased in 2010 at Nai Sa village (said to be from the Bainang mine) showed an argon ratio somewhat comparable to the value obtained from an andesine collected at the mine by Abduriyim in 2008. The two samples from Yu Lin Gu showed very high argon ratios. The three stones from Zha Lin had elevated argon ratios comparable to those obtained from the pale yellow Inner Mongolian andesine examined in 2008.

Although the furnace heating procedure used in this study was different from the laser heating reported in Rossman (2011), a comparison of the data obtained by both techniques on sample GRR 2641 shows consistent ratios within expected variations.

The present study indicates that the Yu Lin Gu and Zha Lin samples tested were not subjected to the heat treatment process usually applied to commercial red andesine. The nature of the Nai Sa-Bainang samples tested is more difficult to establish definitively. Their argon ratios were somewhat higher than those typically found in treated red andesine, but significantly below those observed in material from Yu Lin Gu and Zha Lin.

Diffusion of Ag in Feldspar. The untreated Inner Mongolian andesine contained no detectable silver. After diffusion treatment, the samples' coloration appeared unchanged but they contained surface-conformal concentrations of Ag. Those treated for 31 hours showed a maximum Ag content of ~900 ppmw, and silver was detectable to a depth of 0.7 mm. Samples treated for a much longer duration (180 hours) exhibited a lower maximum concentration of Ag at 200 ppmw, but silver was detectable to a greater depth of ~1.2 mm. For samples treated for both durations, a lower concentration of silver was detected near the surface as compared to several hundred micrometers below it.

The observed diffusion profiles through the sam-

TABLE 3. Argon isotope ratios of andesine reportedly from "China," Tibet, and Inner Mongolia.

Sample no.	Description	Source	Reported location	Test date	$^{40}\text{Ar}/^{36}\text{Ar}$
GRR 2641	Red rough	Andegem, 2008	"China"	July 20, 2009	650
GRR 2921	Red rough	Nai Sa-Bainang, 2008	Tibet	July 20, 2009	1631
72.49 TW	Red rough	Bainang, purchased in Nai Sa, 2010	Tibet	Dec. 23, 2010	1055
A382	Red rough	Yu Lin Gu, in creek, 2010	Tibet	Dec. 23, 2010	11525
29.17 TW	Red rough	Yu Lin Gu, on surface, 2010	Tibet	Dec. 23, 2010	11685
A330	Red rough	Zha Lin, 1.2 m deep pit at mine site, 2010	Tibet	Dec. 23, 2010	3884
A324	Red rough	Zha Lin, 30 cm deep pit under bush, 2010	Tibet	Dec. 23, 2010	6434
A347	Red rough	Zha Lin, on surface at mine site, 2010	Tibet	Dec. 23, 2010	4309
215.12 TW	Pale yellow rough	Litto Gems, 2010 donation	Inner Mongolia	Dec. 23, 2010	>6000

ples suggest that silver substitution in plagioclase is quite high. It is likely even higher than the diffusion profile suggested by the 31-hour experiment, because the drop in silver concentration at the surface of the sample indicates outward diffusion of silver during the experiment. This likely occurred because the vapor pressure of silver at 1170°C is ~0.12 torr, so it distills out of the zirconia carrier as the experiment proceeds. As it is depleted, some of the silver in the plagioclase diffuses back down the concentration gradient out toward the surface.

This experiment shows that silver—like copper—can diffuse into plagioclase under conditions that may exist in nature or may be created in the lab.

CONCLUSIONS

Since 2005, gem-quality andesine represented as being from Tibet—mostly red to orange but also showing other colors and sometimes strong color zoning—has been available in the marketplace. This article mainly presents findings associated with Abduriyim's 2010 expedition, which visited two reported Tibetan andesine occurrences, Zha Lin and Yu Lin Gu, located near the previously investigated Nai Sa–Bainang mining area. The group found strong field evidence for a genuine andesine deposit at Zha Lin, but could not confirm the authenticity of the Yu Lin Gu occurrence. No primary andesine-bearing source rocks were found in either area. A more thorough geologic investigation of the region is still needed.

No matrix specimens were seen in the field; however, examination of matrix specimens represented as being from Tibet suggested they had been manufactured. The andesine samples obtained at Zha Lin and Yu Lin Gu by the 2010 expedition—for the most part, rounded pebbles—showed an overall low quality compared to the abundance of attractive gems represented as Tibetan in the marketplace. There was an overlap in gemological properties between the Tibetan and known-treated samples obtained by the expedition. The chemical properties also overlapped, except for the presence of significant amounts of Ag only in the Yu Lin Gu samples and a possible depletion of Ba in the known-treated stones. Multivariate statistical analysis of the chemical data gave a 30% overlap in the Tibetan and known-treated stones. A preliminary SEM investigation suggested that both the Tibetan and known-treated andesines may host surface residues consisting of

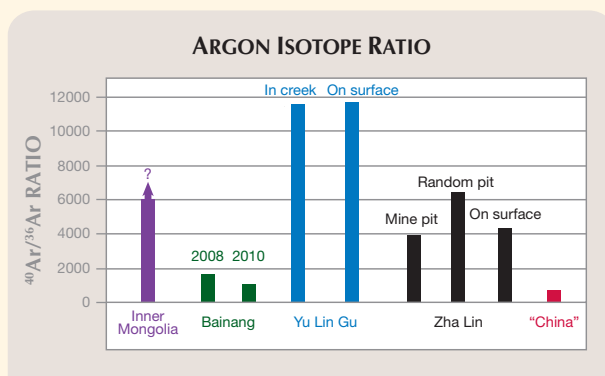


Figure 17. Elevated argon isotopic ratios were obtained for pale yellow andesine from Inner Mongolia, as well as red samples from Yu Lin Gu and Zha Lin that were collected during Abduriyim's 2010 expedition. Red andesines reportedly from the Bainang mine contain significantly less ⁴⁰Ar, while a "Chinese" red sample obtained from Andegem in 2008 shows a low ratio indicative of high-temperature heating.

copper-rich micro-clusters and patches of silica, but the crystallinity of the silica appeared different in the different sample types. Glassy surface residues were present on some of the Tibetan and known-treated stones. Powder X-ray diffraction data showed some overlap between Tibetan and known-treated stones. Argon isotopic studies indicated that the samples tested from Zha Lin and Yu Lin Gu (none of which had glassy surface residues) had not been exposed to the high temperatures associated with diffusion treatment.

Although some of the evidence obtained from field and laboratory studies is supportive of genuine natural-color andesine from Tibet, the inconclusive and sometimes contradictory results described above and in other studies (e.g., Rossman, 2011; Peretti et al., 2011) indicate that not all the stones represented as Chinese or Tibetan are authentic. Our research has shown that to date there is no reliable, realistic way to separate the natural Tibet material from the treated stones from Inner Mongolia. It is possible that this separation might be made using a combination of several advanced techniques, but most of them are expensive, destructive, and/or not widely available, so they are impractical for individual andesines. Therefore, at this time, GIA's laboratory reports on these stones state "Color origin cannot currently be determined." Additional research is needed to establish unambiguous identification criteria for stones of natural versus treated origin.

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ACKNOWLEDGMENTS

The authors are grateful to Christina Lu (M.P. Gem Corp., Kofu, Japan) for supporting and organizing the field trip, and to miner Li Tong and his wife Lou Li Ping (Tibet Andesine, Shenzhen, China) for allowing access and guiding us to the localities. Marco Cheung (Litto Gems, Hong Kong) is thanked for arranging a donation of two parcels of Inner Mongolian andesine that were reportedly treated in China. Special thanks to the ARC National Key Centre for Geochemical Evolution and Metallogeny of Continents (GEMOC), Macquarie University, Sydney, Australia, for LA-ICP-MS chemical analyses; to Ross Pogson of the Australian Museum, Sydney, for powder X-ray diffraction analysis; and to Terry Coldham, president of the Gemmological Association of Australia, Sydney, for his cooperation with the copper diffusion heating experiments. Ken Farley at Caltech assisted with the argon isotope measurements. Thanks also to Kousuke Kosuda of the National Institute for Materials Science (NIMS), Tsukuba, Japan, for his help with electron microprobe analyses.

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