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Canada's Diavik Mine

Fabergé Imperial Bodyguards

Responsible Sourcing, Production of Colored Stones

Journey to the Chivor Emerald Mine

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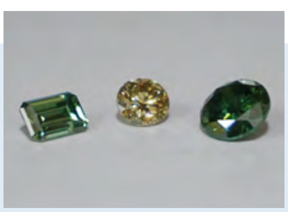

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About the Cover

The lead article in this issue examines the discovery and geology of the Diavik diamond mine, as well as the nature of the operations at this remote site in Canada's Northwest Territories, just 220 km south of the Arctic Circle. The aerial photo on the cover, taken in the summer of 2014, captures Diavik's isolation and the extent of its operations. Photo by Dave Brosha, courtesy of Diavik Diamond Mine.

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Responsible Mining, a Trek to Chivor, and a Dash of Fabergé

The quest for gem-quality natural diamonds is a multi-billion-dollar enterprise—and a stern test of human ingenuity. Any investment in a large, modern mine is by necessity strategic, and made all the more complex when the location is remote and subarctic. Thus it is with the Diavik mine, which sits on a small island on pristine Lac de Gras in Canada's Northwest Territories. Replete with engineering challenges, and the need to accommodate the concerns of the area's indigenous people, Diavik's transition to an active mine in 2003 is a landmark development in the fascinating story of Canadian diamonds.

Our lead article, by Jim Shigley, Russ Shor, Pedro Padua, Mike Breeding, Steve Shirey, and Doug Ashbury, offers a review of this mine's discovery, development, and operations and looks to its planned closure in 2024, when the site will be restored to nearly its original condition. Besides its value as a premier gem diamond source—100 million carats and counting—Diavik is a tantalizing window for geologists into the depths beneath the Canadian Shield. Knowledge acquired from the kimberlites at Diavik allows geoscientists to reconstruct the early history of the North American continent and underscore the supreme value natural diamonds hold for science, beyond their monetary worth as gems.

"A landmark development in the fascinating story of Canadian diamonds..."

In addition to Diavik, we offer articles on a pair of exquisite Fabergé figures, the current state of the colored gem industry's supply chain in terms of corporate social responsibility, the fashioning of an exceptional Australian opal, and a trek to Colombia's Chivor emerald mine in the footsteps of its remarkable manager, Peter W. Rainier.

Our second paper, by Tim Adams and Christel Ludewig McCanless, presents two rare Fabergé hardstone figures depicting the Romanov empresses' Cossack bodyguards. It discusses the design, construction, and subsequent history of the pieces since their creation using Russian-mined gems and metals in the firm's St. Petersburg workshop.

Next, Jennifer-Lynn Archuleta reviews ongoing efforts to establish ethical, sustainable mine-to-market supply chains within the multibillion-dollar colored gem industry. She outlines the challenges the industry faces on its journey to toward greater transparency and traceability in a climate of heightened scrutiny from NGOs, governments, and concerned consumers.

In our fourth paper, Ted Grussing reveals the special considerations he applied to cutting a 3,019 ct gem-quality white opal from Coober Pedy, Australia. He describes how care and attention to detail maximized size and quality, yielding a 1,040 ct finished gem with play-of-color across its entire surface.

Finally, join Robert Weldon and his co-authors on a journey through the early twentieth century history of the Chivor emerald mine and revisit the achievements from a productive and colorful era in Colombian emerald mining.

As always, you'll also find plenty of interesting content in our latest Lab Notes, Micro-World, and Gem News International sections. And don't forget to visit www.gia.edu/gems-gemology for exclusive photos and videos from this issue.

We hope you enjoy our Summer issue!

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Mining Diamonds in the Canadian Arctic: The Diavik Mine

James E. Shigley, Russell Shor, Pedro Padua, Christopher M. Breeding, Steven B. Shirey, and Douglas Ashbury

The Diavik mine, located in the Archean-age Slave geologic province in northern Canada, is one of the world's preeminent sources of gem diamonds. Since mining operations began in 2003, it has produced over 100 million carats of diamonds. This article will review the discovery, development, and operation of the mine, which is situated in a remote subarctic setting in the Northwest Territories. Four kimberlite pipes occur in close proximity—three are being exploited, while the fourth will be brought into production in 2018. Diavik is now expected to operate through 2024; upon closure, the equipment, buildings, and infrastructure will be removed and the land returned as closely as possible to its original condition.

Canada is the world's fourth-largest diamond producer, with most of that output coming from one area near Lac de Gras in the Northwest Territories. The discovery of kimberlite pipes there in the early 1990s led to the development of several major mines. Diamond-bearing kimberlite deposits that can be mined economically are noteworthy, since only about 50 such occurrences have been found worldwide since the 1870s, mainly in Australia, Angola, Canada, Russia, and South Africa (Janse, 2007). As of mid-2016, Canada has three active mines: Ekati and Diavik (figure 1), located about 30 km from each other in the Northwest Territories (figure 2), and the Victor mine in northern Ontario. Snap Lake, recently placed in a care and maintenance status, lies within 80 km of Ekati and Diavik. Two other Canadian mines are under development: Gahcho Kué in the Northwest Territories and Renard in Quebec. Figures from the Kimberley Process (www.kimberleyprocess.com/en/canada) show that Canada produced 11.6 million carats of rough diamonds in 2015, valued at US$1.675 billion.

See end of article for About the Authors and Acknowledgments.

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This article will discuss the discovery, development, and operation of Diavik, one of the richest diamond mines in the world. Over several days in late June 2015, the authors visited the site to capture photographs and gather information on the mining operations. The visit involved tours of the open pit and underground workings, the processing and recovery plant, and the facility in Yellowknife where diamonds are cleaned and sorted for distribution (figure 3). In this article, we focus on the unique engineering challenges in developing the Diavik mine and recovering diamonds from beneath a lake in a harsh subarctic environment, all while doing so in a way that protects the environment, ensures worker safety, and respects the cultural traditions of the local indigenous peoples.

DIAMOND EXPLORATION IN CANADA

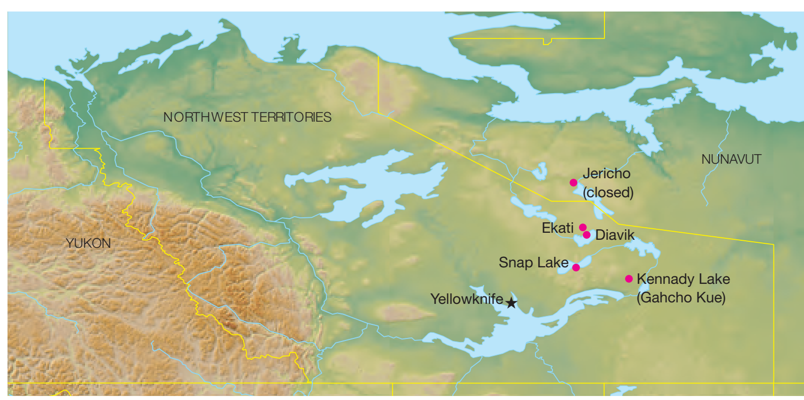
Canada is the world's second-largest country in terms of land area, but until the 1990s it was not considered an important source of gemstones. During the preceding century, alluvial diamonds were occasionally found in scattered locations across southern Canada and the northeastern United States (Hausel, 1995). Their association with glacial sediments in the Great Lakes region led Hobbs (1899) to propose that the diamonds had been transported by the southward

Figure 1. The Diavik diamond mine, shown here in February 2015, is located on a small island in Lac de Gras, approximately 300 km northeast of Yellowknife and 220 km south of the Arctic Circle, in a remote region of Canada's Northwest Territories. Photo courtesy of Diavik Diamond Mine.

movements of glaciers (which covered large portions of Canada during the Pleistocene epoch, from 2.5 million until about 12,000 years ago) from unknown source rocks in the area near Hudson Bay (see also Bell, 1906).

Kjarsgaard and Levinson (2002) presented a comprehensive review of the discovery and development of Canada's diamond mines through the 1990s. Although the north-central areas of the country were known to be underlain by ancient rocks of Archean age—the rocks that also host diamondiferous kimberlites in southern Africa and elsewhere—there was little effort on the part of large mining companies to search for diamonds in the Slave craton (Pell, 1995; Carlson et al., 1999). Along with the vast expanse of territory, the very small target area presented by kimberlite pipes, and the cost of search efforts over a period of years, those authors suggested two additional reasons for the lack of diamond exploration programs in northern Canada. The first was logistical: the remoteness of the area, much of it covered by water, and the harsh climate that limited the field season for exploration. The second reason was the glacial

Figure 2. This regional map of northern Canada shows the locations of Diavik and other diamond mining operations.



dispersal of the contents of exposed kimberlite pipes by the movement of ice sheets away from the original pipe locations. New geological exploration techniques, similar to those being used in Siberia, were needed to search for diamondiferous kimberlites in this type of terrain, which is much different from that of southern Africa (McClenaghan and Kjarsgaard, 2001).

According to Kjarsgaard and Levinson (2002), the modern era of diamond exploration in Canada began in the early 1960s with the traditional search for the diamond "indicator minerals" (such as red Cr-rich pyrope garnet, green Cr-diopside, green olivine, black ilmenite and black Cr-spinel). These minerals, which weather out of kimberlites but are retained as colorful grains in alluvial sediments in far greater abundance than the similarly resistant but much rarer diamonds (Gurney, 1984; McClenaghan, 2005; Shirey and Shigley, 2013). The discovery of these minerals signaled the presence of kimberlites in a particular area, and chemical analysis of them could distinguish those pipes that might contain diamonds. In Canada, the search for these minerals would ultimately involve years of lonely work in a nearly uninhabited and inhospitable region (Krajick, 2001).

The topography of northern Canada has been significantly influenced by periods of glaciation in the geologic past. The land is relatively flat to slightly undulating, marked by low barren hills and shallow bodies of water. In this setting, diamond prospectors had come to believe that sampling glacial eskers (narrow, sinuous ridges composed of sand and gravel sediments deposited by streams from melting glaciers) for indicator minerals might prove successful in locating kimberlites. This had been the case with searching for similar minerals in stream sediments in nonglaciated terrains (McClenaghan et al., 2000; McClenaghan and Kjarsgaard, 2001). Initial target areas included northern Ontario and portions of Quebec, followed by a shift in exploration toward the north and west of the country.

Diamond prospectors who previously found indicator minerals along the Mackenzie River Valley in the Northwest Territories realized that the westward movement of glaciers had transported these minerals from source rocks near the center of the continent. In the early 1980s, improved airborne geophysical survey methods for locating small-target kimberlite pipes over a wide area, combined with a better understanding of how to check sediments from both glacial moraines and eskers, led to preliminary diamond discoveries in various parts of the country.

Figure 3. This selection of rough diamonds is typical of Diavik's production. Photo courtesy of Diavik Diamond Mine.

After these initial finds, however, the idea of a more extensive search for diamonds in northern Canada was met with skepticism. Initial exploration efforts involved several major mining companies, but the search was primarily undertaken by smaller companies and even groups of individual prospectors.

In April 1990, after a decade of exploration across an east-west distance of 1,200 km in the Northwest Territories, came Chuck Fipke's discovery of a bright green Cr-diopside crystal on a ridge at Point Lake, a small, circular crater-like lake just north of Lac de Gras. As this mineral does not survive travel far from its source rock, he concluded that it had come from a kimberlite pipe in the immediate vicinity. This led Fipke and his partner in Dia Met Minerals, fellow geologist Dr. Stewart Blusson, to stake a claim. Years later this area would become part of the Ekati mine (Fipke et al., 1995). Additional heavy mineral samples collected north of Point Lake confirmed the presence of a kimberlite pipe. Partnering with BHP Minerals, a large international mining company based in Australia, they obtained drill core samples from the pipe to better evaluate its mineral content and structure.

In Brief

- Diavik in northern Canada is one of the world's most important diamond mines, with production to date of more than 100 million carats.
- Mining takes place year-round in a remote and hostile subarctic environment.
- Before open-pit mining could begin, retention dikes had to be built to enclose the workings, which were below the water level of Lac de Gras.
- Mining is expected to continue through 2024, after which all infrastructure must be removed and the site returned as closely as possible to its original condition.

In November 1991, BHP announced that 59 kg of kimberlite core samples from the site contained 81 small gem-quality diamonds, and that the company would spend up to $500 million to develop a mine. Over the next 12 months, this stunning development triggered the biggest land rush in Canadian history, as mining companies and individual prospectors staked claims over some 22,000 square kilometers in the north-central part of the country (Krajick, 1994, 2001; Boyd, 2006).

Over the past 25 years, exploration efforts have identified more than 500 kimberlite pipes throughout Canada, with more than 50% containing traces of diamonds. Most of these occurrences are located in the Lac de Gras region near the center of the Slave craton (Carlson et al., 1999). Few of these pipes are directly exposed at the surface; most are buried beneath bodies of water, and they have been revealed by geophysical and field sampling techniques. Because kimberlites weather and decompose faster than much older surrounding rocks, the pipes often occur in topographic depressions beneath lakes. By the end of 1994, a total of 39 kimberlites had been identified in the Lac de Gras area, including what would become the country's first diamond mine: Ekati, which opened in the fall of 1998. Because these kimberlite pipes were located in an ecologically sensitive portion of northern Canada, the mining ventures had to undergo an extensive environmental, economic, and social review involving several government agencies and local indigenous communities before proceeding with development.

DISCOVERY AND HISTORY OF DIAVIK

By early 1992, Aber Diamond Corporation had staked a claim to 3,250 square kilometers in the Diavik area. The company began a helicopter-borne magnetic survey (in partnership with Kennecott Canada, the exploration arm of Rio Tinto) to identify target locations as prospective kimberlite pipes (Carlson et al., 1999; Graham et al., 1999). A Yellowknife-based exploration company (Covello, Bryan & Associates) was hired for the prospecting activities. Ground, gravity, and other geophysical measurements were also made to confirm that the targets were kimberlites, and to better delineate the size of potential pipes. Samples collected from glacial till, streams, and beaches around these locations were analyzed for indicator minerals. When potential targets were detected, they were ranked in order of priority for additional study based on their geophysical characteristics and proximity to the indicator minerals. Core drilling of the most promising sites was then carried out to determine the lateral extent of the pipe and its micro-diamond content.

Indicator minerals were first discovered on the Diavik property in 1994, near what was then designated as the A21 anomaly, but the decision was made to first core-drill the nearby anomaly that later became the A154 (South) pipe. This drilling produced a section of kimberlite core that broke open to reveal a 2.5 ct diamond crystal (Graham et al., 1999; Tupper and Neamtz, 2002). Considering the rarity of diamonds in kimberlite pipes, to encounter such a large crystal in a random core section was remarkable. In 1995, the adjacent A418 pipe was evaluated for its diamond potential. Drilling revealed that the geomagnetic anomalies were small, steeply inclined, semicircular volcanic pipes that became narrower with depth.

By 1995, four diamond-bearing kimberlite pipes had been located—all beneath the waters of Lac de Gras. The pipes are adjacent to the lake shoreline and lie within 4 km of one another. Additional core drilling was carried out to carefully delineate the sizes and shapes of the pipes, and their potential diamond grade was estimated from analyzing the drill cores. Between 1996 and 1997, the initial pipes—A154 (which was later found to be two adjacent pipes) and A418—were accessed by several large-diameter (approximately 15 cm) holes, core drilling to depths of about 250 meters, and then by underground tunnels excavated 150 meters beneath Lac de Gras. From these activities, 5,937 tonnes of kimberlite ore were recovered from the A154 South and A418 pipes. Evaluation of this bulk sample was critical to determining whether the pipes contained enough high-quality diamonds for mining to be economical. Some of the recovered ore was analyzed at the company's pilot processing plant in Yellowknife, and the rest was split into two portions for separate evaluation at both the Yellowknife plant and the nearby Ekati mine. In 1998, analysis of 21,013 carats of diamonds (one-third of which were gem quality) recovered from the bulk ore sample provided the first evidence of the mine's economic potential.

Earlier in 1995, hydrological and geotechnical studies were begun to assist in the conceptual design and development of both the open-pit and planned underground mining operations. These studies have continued to the present day.

Despite the environmental and engineering challenges for large-scale mining in this remote region, Rio Tinto and Dominion Diamond Corp. (formerly Aber) established a formal joint venture in 1999 to develop the property. Rio Tinto managed and operated the mine through a wholly owned subsidiary, Yellowknife-based Diavik Diamond Mines Inc. Diamond production would be divided between the two organizations, with each independently marketing its own share.

In addition to examining the economic feasibility of operating a diamond mine under arctic conditions, the developers conducted environmental risk analysis between 1997 and 2000. A scientific assessment of all aspects of the regional environment provided a baseline to measure the impact of the subsequent construction and operation of the mine. Agreements also needed to be signed with the five First Nations—the Lutsel K'e Dene First Nation, the Yellowknives Dene First Nation, the Tlicho Government, the Kitikmeot Inuit Association, and the North Slave Metis Alliance—which had inhabited the area for centuries. These groups sought the protection of land and lakes and a share of the economic benefits from mining. In 2000, formal permission was granted to the joint venture to begin mine construction. This included an environmental agreement with the Canadian government, and a socioeconomic monitoring agreement with the government of the Northwest Territories.

Between 2000 and 2003, approximately CAD$1.3 billion was spent building the mine infrastructure, one of the largest capital investments undertaken in the history of Canadian mining. This included a plant to process the kimberlite ore and recover the diamonds, office and accommodation buildings for several hundred staff, utilities (electric power and heat generation, water supply, and wastewater treatment), bulk fuel and explosive storage, a maintenance shop, a containment area for storing the processed kimberlite, and an airstrip capable of handling cargo and passenger aircraft. Development of the site occurred in a relatively uninhabited arctic tundra setting—the closest indigenous community was 190 km to the southwest. Everything needed to construct and maintain the site had to be flown in from Yellowknife or trucked over an ice road during wintertime. Transition from a construction project to active diamond production commenced in January 2003, with an expected mine lifetime of about 16–22 years. Sales of the first rough diamonds began in the summer of that year.

In 2006 and 2007, another group of bulk kimberlite samples was collected underground at each of the three pipes (A154, A418, and A21) to determine underground mining conditions, to compare the impact of drill and blast mining versus machine mining on diamond value, and to provide about 15,000 carats from each pipe for additional estimations of rough diamond values. With the exception of the data on diamonds from A21, these 2006–2007 estimates have been superseded by more recent information obtained from actual production parcels from A154 (117,000 and 118,000 carats in May 2013) and A418 (186,000 carats in May 2012). Since 2003, the mine has yielded 100 million carats of rough diamonds, with the largest crystal found to date weighing 187.7 ct (figure 4). Named the "Diavik Foxfire," it was produced between May 31 and June 6, 2015 (see the Lab Notes section of this issue, pp. 188–189). Previously, the largest gem-quality diamond recovered weighed 151 ct.

GEOLOGICAL SETTING

This kimberlite province, discovered in 1991 and measuring about 400 × 750 km, is a portion of the Slave craton, a region of the continental lithospheric plate (also known as the Canadian Precambrian Shield) that has remained geologically stable since Archean times 2.5 to 4 billion years ago (Pell, 1997; Bleeker, 2002; Davis et al., 2003; Canil, 2008; see boxes A and B and figure 5). In this region, the rocks that compose the ancient crust are exposed at the surface by glaciation. The craton consists of granites and gneisses, with younger volcanic and metasedimentary rocks deposited on them. It sits above a mantle "keel" (a downward-protruding thickened portion of the lithosphere) where relatively low heat-flow and reducing conditions have remained suitable for diamond formation and preservation for an extended period of geologic time (Shirey and Shigley, 2013). Explosive kimberlite magma eruptions rising through this keel zone brought diamonds to the crust. This is a typical setting for kimberlite pipes in Archean cratonic rocks worldwide.

Subsequent to kimberlite pipe emplacement, this portion of Canada was covered by a glacial ice sheet that culminated about 20,000 years ago. As stated above, this glaciation removed much of the topography of the area, including the upper portions of the kimberlite pipes. On East Island, where the Diavik mine is located, the kimberlite pipes are hosted in approximately 2.5-billion-year-old Archean granitic host rocks as well as some younger metasediments. Several Proterozoic diabase dikes cut through zones of structural weakness in these granitic rocks—these same zones may have been where exploding kimberlite magmas broke through to the surface.

Kimberlite pipes are the near-surface conduits of kimberlite volcanoes. As no such eruption has ever been observed, the geological understanding of these events is based almost entirely on observations of the pipes' complex vertical structure obtained from drill core sections or exposed during underground mining, and from petrographic analysis of rocks found within the pipes (Moss et al., 2008). As in many other kimberlites worldwide, a complete understanding of the magma eruption process is often hindered by subsequent erosion, which removes important upper sections of a pipe.

More than 400 kimberlite pipes are now known in the Lac de Gras area (W. Boyd, pers. comm., 2016). They are distributed along a northwest-trending axis extending more than 120 km. Only a few are economic to mine for diamonds. The Diavik mine lies near the center of the Slave craton. The geology of the four kimberlite pipes on the mine property is now well understood based on field studies conducted over the past two decades (Graham et al., 1999; Bryan and Bonner, 2003). Kimberlites at the mine are interpreted as representing coherent pyroclastic and volcaniclastic types of igneous rocks, and the pipe emplacement has been dated at 55 ± 5 million years ago, during the Eocene epoch (Graham et al., 1999). The pipes are up to 20,000 square meters at the surface, and they extend down to depths of at least 600 meters. Each has a different mixture of kimberlite types and country rock. Field studies of the A154 pipe by Moss et al. (2008) revealed a poorly sorted massive volcaniclastic kimberlite overlain by a better-sorted stratified volcaniclastic kimberlite containing variable proportions of consolidated mud and, at the top of the sequence, a graded pyroclastic kimberlite. The pipes are capped by several meters of glacial till, a thin layer of lacustrine sediments, and 15–20 meters of lake water. Moss et al. (2008) proposed a six-stage explosive eruption model for the A154 pipe:

1. Initial kimberlite eruption and excavation of the pipe to form a vertical pipe beneath a surface crater
2. Collapse of the pyroclastic gas cloud from above, and partial infilling of the upper portion of the pipe with massive kimberlite from below

Figure 4. The 187.7 ct "Diavik Foxfire," discovered in spring 2015, is the largest gem-quality rough diamond found to date at the mine. Photo courtesy of Rio Tinto Diamonds.

BOX A: THE SLAVE CRATON: AN ANCIENT REMNANT OF EARTH'S EARLY CRUST

Seismically stable geological areas on Earth are known as cratons. These vestiges of ancient rock are the rarest, smallest, and oldest remnants of continental crust and immediately underlying 150–200 km of mantle (together known as the continental lithosphere). The Diavik mine lies in the middle of the Slave craton, which derives its name from the Great Slave Lake at its southern border. An exciting feature of the Diavik kimberlites, besides their abundance of diamonds, is that the kimberlite punctures and carries deeply derived pieces of the mantle from Earth's ancient past. The geological history preserved in the Slave craton offers a fascinating record, one that can be read from the complicated surface geology and especially from the deep mantle-derived rock samples brought up within the kimberlite.

Like other cratons (e.g., the Superior in Canada, the Kaapvaal in South Africa, or the Pilbara in Australia), the Slave craton is a complicated collage of different continental terranes created at different times and forced together over more than two billion years. The surface geology reveals the different ages of these units, and how they fit together like puzzle pieces. The vertical sampling of diamonds and mantle and crustal rocks by kimberlite that is then erupted to the surface becomes an invaluable tool to peer through the younger crustal rocks, which have a different surface geology from those at 30 to 150 km depths. With enough kimberlites and enough diamonds made available for study from mining operations, a vertical cross section of the craton can even be constructed (figure B-1).

At the surface of the Slave craton, the oldest rocks, some ranging in age up to 4.2 billion years, are exposed in the Acasta Gneiss Complex (AGC) on the far west side of the craton and in a north-south belt of gneisses known as the Central Slave Basement Complex (CSBC) in the center. Within these ancient complexes themselves, almost 1.4 billion years of geological evolution can be measured by radiometric dating methods. To the east of the CSBC, the surface rocks are all much younger, more granitic, and clearly related to the modern process of plate tectonic subduction that operated from the craton's eastern side about 2.5 billion years ago (Bleeker, 2002). Surprisingly, the diamondiferous kimberlites in the Slave craton have erupted through the craton east of the CSBC—coming clearly through parts of the craton that are dominated by younger rocks (most typically 2.5 billion years). Because the diamonds in the Diavik and other kimberlites are much older (up to 3.5 billion years) and similarly old mantle xenoliths occur in the kimberlites, the deep mantle keel must reside some 100 km below younger crust. The surface geology of the Slave craton, therefore, is an asymmetrical geological construct whose depths are known because of diamondiferous kimberlite eruptions.

3. Flows of debris from the surrounding crater walls and further infilling of the pipe, leading to the formation of the stratified kimberlite
4. Alteration of rocks within the crater by hot circulating fluids originating from groundwater interacting with the underlying kimberlite magma
5. Deposition of sediments in the upper portions of the crater, which now lie beneath a lake
6. Deposition of pyroclastic kimberlite in the crater by material ejected from adjacent kimberlite eruptions

At Lac de Gras, glaciation removed the top portions of the pipes. When exposed at the surface, kimberlites weather and decompose, becoming softer than the surrounding country rocks. With the retreat of the glaciers, the pipe locations often became depressions in the land surface, which filled with water to become lakes. The lakes at pipe locations are generally deeper than those formed by just glacial action.

Careful documentation of the different types of kimberlite (and other rocks) within a pipe is important because these factors can exert some control over the size and abundance of the diamonds, and on the processing of the material as kimberlite ore. This typically involves analyzing hundreds of ore samples.

LOCATION AND ACCESS

The Diavik mine is located at 64°29′46″ N and 110°16′24″ W, on a small island in Lac de Gras about 300 km northeast of Yellowknife (the capital of the Northwest Territories), and 220 km south of the Arctic Circle. The mine is situated in a continuous permafrost zone 100 km north of the tree line (the latitude above which trees cannot survive the cold temperatures). The permafrost layer extends from two meters below the surface down to a depth of about 250 meters. The bedrock consists of glacially eroded granite that is covered in many places by glacial till. The till is composed of sand, gravel, cobbles, and boulders in varying proportions in a rock flour matrix. Near the lake shorelines, the finer material has been washed out, leaving mainly boulders. Beneath the lakes, the till is overlain by several meters of fine sediment.

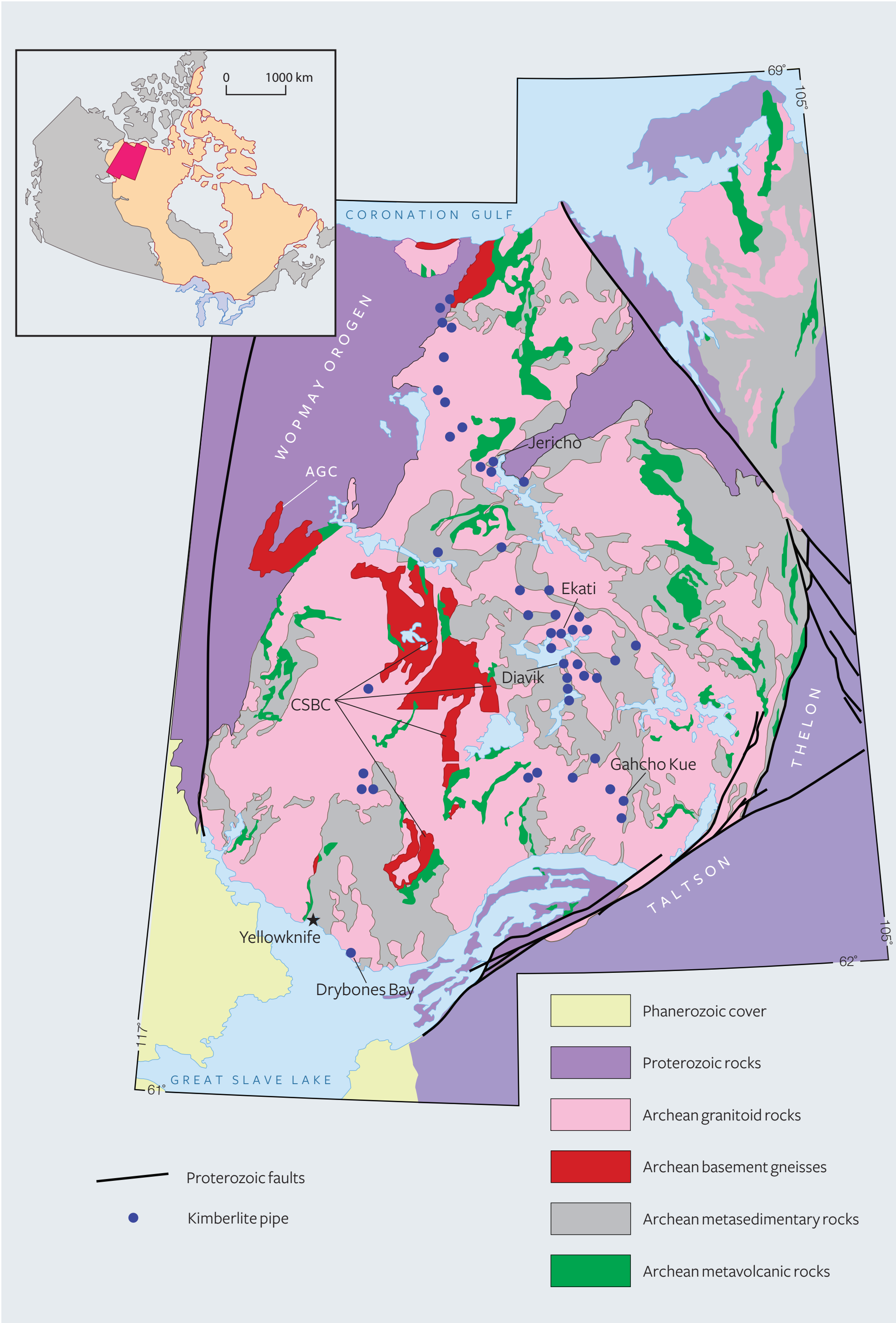


Figure 5. This simplified regional geological map shows the major rock units within the Slave Structural Province. Note that the basement gneisses of the Acasta Gneiss Complex (AGC) and the Central Slave Basement Complex (CSBC)—shown for both in red— contain some of the oldest rocks on Earth (up to 4.2 billion years) and that the Diavik mine is found to the east in much younger Archean rock (2.5–2.7 billion years). Yet we know that Diavik and the neighboring Ekati mine contain diamonds as old as 3.3–3.5 billion years. Thus they are found in old mantle at depths that might be related to the old surface rock to the east. See the cross section in box B. Modified from Bleeker (2002) and Helmstaedt (2009).

Summers at the site are short and cool, while the winters are long and extremely cold. In winter it is not unusual to have weeks with temperatures between –35°C and –40°C, with frequent strong winds making these temperatures feel even colder. Snow may fall in any month of the year, but it normally occurs between October and April. The region receives only about 300 mm of precipitation per year, mainly in the form of snow, so it can be considered an arctic semidesert. Daylight ranges from about four

BOX B: AGES OF THE DIAVIK DIAMONDS AND RELATIONSHIP TO THE SLAVE CRATON

The kimberlite magmas at Diavik intruded 55 million years ago and are thus much younger than the Archean craton. The kimberlites are the transporting mechanism for the much older diamonds and indicator minerals that formed deep within the mantle of the craton. These diamonds are xenocrysts in the kimberlite, as are the indicator minerals. Age relations have been established through geochronology, which uses radioactively decaying isotopes of elements such as rhenium and uranium to measure the age of the kimberlite, the mantle rocks that are the source of indicator minerals, and mineral inclusions in the diamonds. These relationships have been well studied from samples provided by Diavik mining operations. Through radiometric age-dating methods on sulfide mineral inclusions (chiefly the long-lived radioactive decay of rhenium to osmium) in otherwise gem-quality diamonds, some of the oldest diamonds ever formed (3.3 to 3.5 billion years old) have been found in Diavik and its nearby counterpart, the Ekati mine (Westerlund et al., 2006; Aulbach et al., 2009). But age dating also shows that diamond formation in this portion of the deep mantle keel has been episodic and occurred in pulses that extend to as recently as 1.8 billion years ago. Any Diavik diamond in a ring will be at least one-third as old as the earth itself, and possibly three-quarters of its age.

An interesting and perhaps unique feature of Diavik and other Slave craton diamonds is their direct connection to the deep mantle conductors that trace the starting material to form diamond. Electrical sounding methods in geophysics, known as "magnetotellurics," deployed on the scale of the entire craton can detect connected electrical pathways between the nonconductive mantle minerals. This occurs along grain boundaries in the mantle rock. Carbon in the form of soft, smearable graphite can provide an electrically conductive pathway if it occurs in high enough concentrations. The outline of the conductive region at depth in the mantle almost perfectly encompasses the occurrence of diamondiferous kimberlites at the surface—thereby supporting a possible link between the carbon content of the deep mantle keel and diamond crystallization (Jones et al., 2003).

Another interesting feature of Diavik diamonds is the high proportion of "coated" crystals—gem-quality diamonds that have been overgrown with younger cloudy rims. These rims are cloudy because of abundant microinclusions of fluid whose composition is often salty or even briny. A recent study has shown that these rims represent a much more recent growth phase of diamond in the deep mantle keel, perhaps as young as 0.2 to 0.4 billion years (Weiss et al., 2015). This age is so recent that it can be related to known plate tectonic reconstructions, offering evidence of the subduction of seawater below and into the mantle keel by the underthrusting of a seawater-containing oceanic slab, more than 1,000 km east of where seawater is found. While seawater subduction is a well-known geological process, direct examples are rare and poorly studied. The Slave craton cross section (figure B-1) shows that a similar form of more ancient underthrusting occurred 1.8 billion years ago.

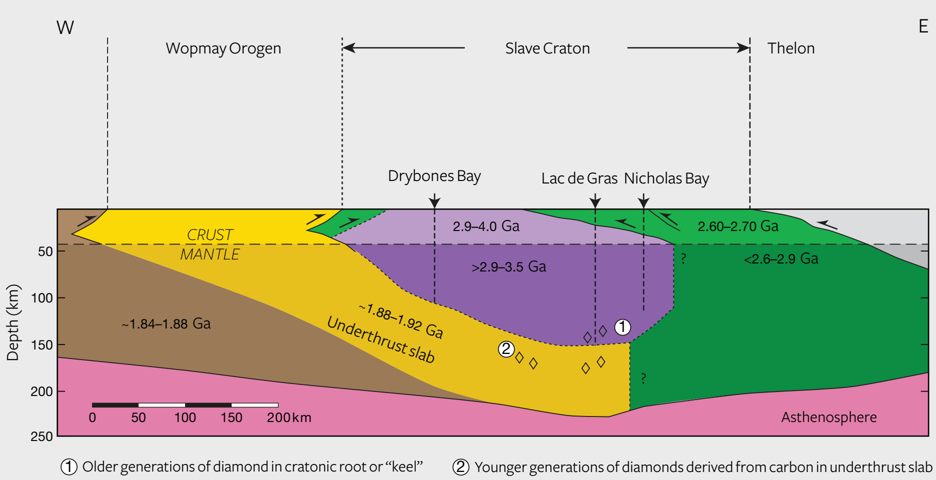


Figure B-1. Cross section of the Slave craton, constructed from surface geology, geophysics, and samples (mantle rock and diamond) provided by kimberlite eruptions and mining operations. Much of the detailed structure and age information between 30 and 250 km depths is only possible because suites of diamonds have been analyzed. Simplified from Helmstaedt (2009).

hours per day in winter to as much as 20 hours per day in summer. Throughout most of the year, the mine can only be reached by air. For a brief time in the winter, an ice road provides vehicle access for thousands of tons of equipment, supplies, and fuel (box C). There is no regular road network in this part of Canada.

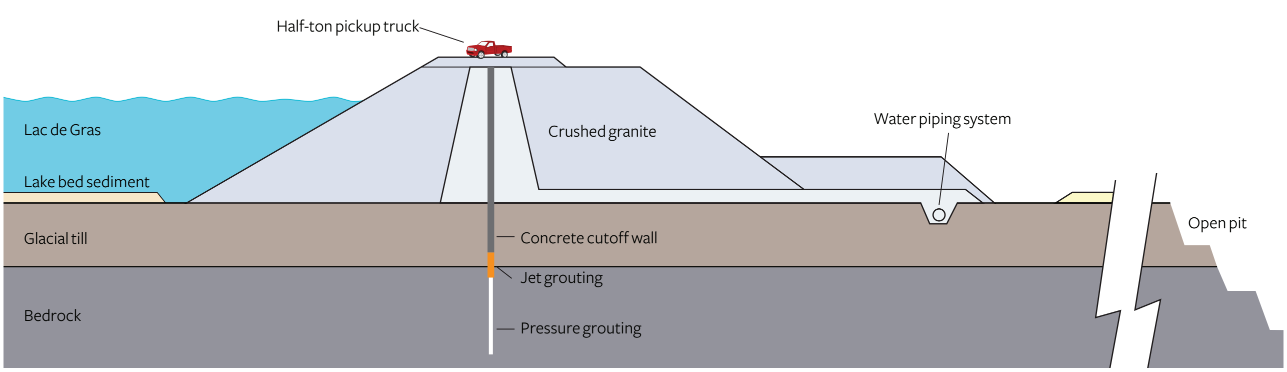
MINE DESIGN

The fact that the four kimberlite pipes were located beneath Lac de Gras (figure 6) posed an engineering challenge if the pipes were to be exploited. The option of accessing and mining the pipes underground from an onshore portal tunnel was ultimately rejected because it would require leaving too much valuable kimberlite ore in place for structural support directly beneath the lake bed. Therefore, a traditional open-pit approach was chosen to remove the kimberlite from the upper portions of the pipes. However, this would require the construction of specially designed dikes surrounding the pipes to allow the open-pit mining of ore bodies that would otherwise be underwater. This required dredging of the lake, placing several million tons of crushed rock into the lake to create the dikes themselves, anchoring the dikes to the bedrock, transferring fish from the enclosed areas back into the lake, and removing several million cubic meters of water from the enclosed areas. Particular challenges included building the dikes without direct access to the bedrock beneath the lake, working during winter months of intense cold and extended darkness when the lake surface would be frozen, preventing debris from contaminating the lake, the use of local material for dike construction (blasted and crushed granite taken in stages from the open-pit locations), and a heavy reliance on an indigenous community workforce with no experience in heavy civil construction (Olive et al., 2004).

Figure 6. This photo, taken from space in August 2014, shows the A154 (top) and A418 (bottom) open pits on the right side of the image. Since the kimberlite pipes were initially covered by Lac de Gras, it was necessary to first construct dikes around the pipes to prevent water from flooding the open pits and underground mine workings. The A21 kimberlite pipe is also under the lake—its location is indicated by the blue dot. Photo courtesy of Diavik Diamond Mine.

The retention dikes around the kimberlite pipes prevent water from flowing from Lac de Gras back into the open pits and the underground workings. Figure 7 shows that the dike is constructed with a flexible concrete water barrier that is anchored to the pressure-grouted bedrock. This wall is supported on both sides by a large volume of crushed granite waste

Figure 7. This cross-section illustrates the design of the water retention dikes that were built around the kimberlite pipes to allow open-pit and underground mining operations. Construction of the dike beneath the lake and across small islands presented engineering challenges. Diagram courtesy of Diavik Diamond Mine.



Box C: The Arctic Ice Road

Figure C-1. This map, taken from Braden (2011), shows the arctic ice road that extends north from Yellowknife.

Based on initial assessments of diamond deposits in the Canadian north, it was evident that the kimberlite pipes could only be exploited by large-scale operations. This meant moving building materials, machinery, heavy equipment, and supplies over long distances to the mining sites over a period of many years. The terrain in this very remote region is impassable by large vehicles for much of the year, and flying is often the only way to transport people and supplies. Yet this mode of transportation was impractical and uneconomical, given the volume and heavy weight of material needed at the mine sites.

Most of the tundra in this region is permanently frozen, but during the brief summer months the permafrost thaws slightly. Because the underlying ground is frozen, water cannot sink any lower and so it forms shallow lakes and marshes. Due to the marshy tundra and numerous lakes, movement of large equipment and supplies by truck depends on the creation of an ice road that operates for only eight weeks during the winter months. With the arrival of very cold temperatures in November, the lakes and marshes become completely solid. By February, the ice on the lakes thickens to more than a meter and becomes capable of supporting heavy trucks.

In 1982, a winter road to service the mining areas was constructed from just north of Yellowknife to Contwoyto Lake, a distance of approximately 600 km (figure C-1). This is the longest heavy-haul ice road in the world, and 85% of it runs over frozen lakes. The road must be rebuilt every year between November and January. Using snowplows, crews work through 20-hour nights, enduring wind chills that can reach –70°F, to create a 50-meter-wide path. Over the frozen lakes, the road consists of two lanes in each direction, but there is only one lane in each direction over land (figure C-2). The road is open for about eight weeks a year, so planning and scheduling of traffic is critical to sustain the diamond mines for the coming year. Using the road, the Diavik mine is approximately 425 km from Yellowknife.

The winter road is privately owned and maintained by a consortium of major mining companies. Use of this shared lifeline requires special safety training and licensing for all truck drivers. Three maintenance camps are located along the route. Loaded trucks must maintain a 500-meter separation and limit their speed to 15 to 20 miles per hour to prevent damage to the roadbed. A maintenance crew travels the route each day to check ice thickness, using ground-penetrating radar to ensure the trucks can be supported. A dispatch office controls the flow of truck traffic, and the consortium maintains a small security force that monitors operations. With warmer temperatures melting the ice in April, the road can no longer be used. Any heavy equipment, spare parts, construction materials, fuel, explosives, or bulk supplies needed at Diavik and other mines throughout the year must be brought in before then. Of special concern to the indigenous communities along the route are fuel spills that would damage the environment.

In 2014, the ice road operated for a period of 60 days during February and March, with a daily average of 118 truckloads carrying about 35 tonnes per load. A total of 7,069 northbound loads carried 243,928 tonnes of supplies. Braden (2011) provides many interesting stories and insights about the history, construction, and operation of this important economic lifeline for the arctic region of Canada.

Figure C-2. These photos show a section of the arctic ice road, by which fuel, equipment, and supplies are brought by large trucks to the Diavik and other mines in northern Canada. Photos courtesy of Diavik Diamond Mine.

Figure 8. The wind farm, with its four large turbines, produces a significant amount of electrical power for the Diavik mine. After the rest of the facility is dismantled and removed with the end of mining, expected in 2024, the wind farm may be donated to a local community to provide electrical power. Photo courtesy of Diavik Diamond Mine.

rock. Several hundred sensors continually monitor temperature, pressure, and ground movement to ensure the structural integrity of the dikes. The ground that acted as the dike foundation was permanently frozen beneath the land surface but not beneath the lake, so special equipment was needed to maintain the permafrost in those locations. Where the dike crosses an island, special refrigeration systems known as "thermosyphons" were installed to remove heat and allow the permafrost below the lake to remain frozen.

The two initial crushed-rock dikes (surrounding the A154 and A418 pipes) total more than five kilometers in length. They stand as high as 32 meters above the lake bed and are wide enough to allow two large vehicles to pass one another. The dikes were constructed using 4.5 million tonnes of granite waste rock.

Because it is so remote, the mine must operate as a self-contained community. The site covers 10.5 square kilometers and contains a dormitory complex, a dining area, recreational and education facilities, an office and maintenance building, a warehouse, and an enclosed maintenance facility where even the largest hauling trucks used at the mine can be worked on year-round. Emergency response and medical services are also available. A 1,600-meter airstrip on the site can accommodate large transport aircraft throughout the year. All principal mine buildings are heated by a boiler plant and connected by elevated, well-lit enclosed corridors so that workers can pass from building to building without being exposed to the harsh winter climate.

Minimal amounts of water are taken from Lac de Gras. A system has been constructed around the island to collect water for reuse or for cleaning in a treatment plant before it is returned to the lake. A separate plant treats all domestic sewage.

A diesel power plant generates electricity for the entire site. A year's supply of diesel fuel is stored onsite for the power plant as well as the mining vehicles. Excess heat from the power plant is used to warm some of the buildings and to heat water used in processing the kimberlite ore. In September 2012, a wind farm (figure 8) was added to provide a renewable source of electrical energy via a wind-diesel hybrid power plant. The wind farm, the first of its kind in the Canadian subarctic, lowered carbon emissions from the mining operations and reduced the need for diesel fuel to be hauled in.

A separate plant produces crushed granitic rock for dike construction, maintenance of the airport runway and road surfaces, and for use underground to backfill the open tunnels and other workings once the kimberlite ore is removed. Explosives used in mining operations are stored in a secure facility on-site.

MINING AND PRODUCTION

Operations. Open-pit operations on the two ore bodies of the A154 pipe began in January 2003, and mining of the A418 pipe followed in 2007 (figure 9). This type of mining was economically viable because the tops of the kimberlite pipes were within 20 meters of the surface, minimizing the amount of waste rock that had to be stripped away to expose them (figures 10 and 11). Kimberlite ore and granite rock overburden from the pits are hauled away by vehicles, without a system of ore buckets or conveyor belts. As surface mining is more economical than underground operations, the intent was to remove as much kimberlite ore as possible from the open pits over time. But as the pipe became narrower with depth, a point would be reached

Figure 10. Kimberlite is no longer mined from either the A154 or A418 open pits—only from underground workings directly underneath. In this photo, entrances to the underground workings can be seen at several places along the pit walls. The structural integrity of the open pits is constantly monitored to ensure that the walls have not been breached by water from the lake, which would cause flooding of the underground workings. Photo by James Shigley.

Figure 9. Aerial view of the A154 and A418 open pits (top and bottom, respectively). Photo courtesy of Diavik Diamond Mine.

Figure 11. This view of the A418 open pit shows several of the mining benches as well as the access road that originally used to remove kimberlite ore from the pit and is now used for the underground workings. The pickup truck gives some indication of the benches' height. Photo by James Shigley.

Figure 12. The A21 kimberlite pipe lies beneath the still-frozen waters of Lac de Gras. Its location is indicated by the red arrow. The future water retention dike will extend from the land at both edges of the photo to the nearer of the two islands. Once the dike is constructed, open-pit mining of the pipe can begin. Photo by James Shigley.

where ore could no longer be removed by vehicle haulage, and surface mining would then cease. In 2012, after three years and a cost of CAD$800 million, Diavik completed the transition to underground operations for the three pipes being exploited.

In the fall of 2014, Rio Tinto announced plans to develop the fourth kimberlite pipe on the property. Construction of the dike surrounding the A21 pipe will take four years; it will extend 2.2 km and require 3 million tonnes of crushed granite (figure 12). Production from the A21 pit is scheduled to begin in late 2018. Output from this pipe will not appreciably extend the life of the mine. Rather, it will offset the approaching decline in production from the underground operations and allow a continuation of existing kimberlite ore levels through the processing plant for several years.

Diavik's original plan called for the eventual development of underground mining operations, primarily by ore trucks driving down a tunnel from the surface (figure 13). Prior to tunneling, an extensive geotechnical survey of the hydrogeology of the ore bodies and surrounding host rocks was carried out. The design of the open pits and the choice of surface mining methods took into account that the pits would be directly above the underground workings. To date, some 20 km of interconnected underground tunnels have been constructed. These heated and ventilated

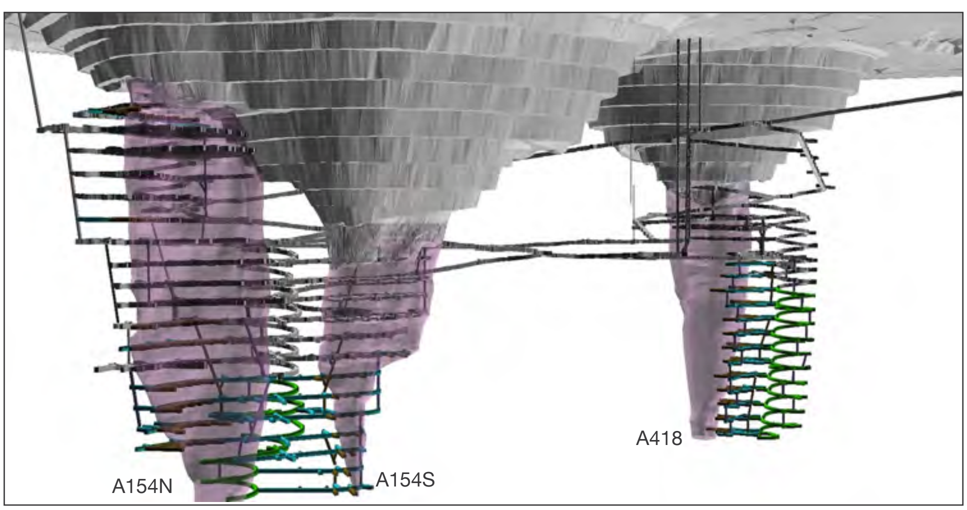


Figure 13. A computer-generated plan of the underground workings that lie below the two open pits of A154 (left) and A418 (right). The workings shown in black are existing tunnels, whereas those in blue-green represent future tunnels that have not yet been installed to reach lower portions of the kimberlite pipes. The long straight tunnel that slopes upward to the right side of the image is the access tunnel. Image courtesy of Diavik Diamond Mine.

Figure 14. View of one of the underground tunnels that extend across the entire diameter of a kimberlite pipe. The tunnel's width and height must accommodate a mining vehicle. Photo by James Shigley.

tunnels include rescue bays where miners can retreat for safety in emergencies, vehicle repair shops, ore passes, ventilation systems, water pumping stations, and storage areas (figures 14 and 15). The underground tunnels were designed to prevent rock in the overlying open pits from subsiding. Although surface mining of A154 and A418 has finished, the pits are the secondary access to the current underground workings via two entrance portals. Continuous monitoring of the now-unused open pits ensures the structural integrity of the pit walls, preventing breaching of the dikes from the surrounding lake and flooding of the underground workings.

Two types of underground mining were selected based on safety, cost, and other considerations. A technique known as blast-hole stoping (BHS) was chosen for A154N because of the stronger, more competent kimberlite rock in this pipe. It is a bottom-up bulk-mining method in which several days of ore production can be created with a single explosion. Holes are drilled vertically from a higher stope (mining cavity) and filled with explosives. When blasted, the broken ore falls to a lower stope, where it can be removed by a scoop loader and ore hauler. Once all the broken ore is removed, the open lower stope is completely backfilled with cemented waste rock, and the process is repeated at the higher stope.

A top-down bulk-mining method known as sublevel retreat (SLR) is used in the A418 and A154S pipes, where the kimberlite ore is weaker but contained within a more competent granite host rock. In this method, a series of horizontal tunnels on a single level is excavated into the pipe, and sections of ore above the tunnels are broken up using explosives. The broken ore falls into the tunnel and is removed. Once all the ore on the level is removed, a new set of tunnels is created farther down in the pipe, and the excavation process is repeated. The process creates a large open space within the pipe.

All three pipes are being excavated concurrently, and a mixture of both "hard" and "soft" kimberlite ore is sent through the processing and recovery

Figure 15. When a tunnel is excavated, this machine is used to install a metal safety screen to prevent debris from falling from the walls or ceiling. Photo courtesy of Diavik Diamond Mine.

Figure 16. A long straight haulage tunnel is used to access the underground workings and haul kimberlite ore from the workings to the surface. Photo courtesy of Diavik Diamond Mine.

plants. Although the mine was originally designed to handle 1.5 million tonnes of ore, this capacity was expanded to 2 million tonnes through operational improvements without the need for additional capital investment (Diavik diamond mine: 2014 sustainable development report, 2015). Kimberlite ore and waste rock are brought from the underground workings to the surface by haulage trucks using three portal entrances, and the material is dumped in a designated location on-site. Larger trucks haul the ore to the processing plant, and any waste rock goes to a separate dump location (figures 16 and 17). The decision to use trucks to haul ore and waste rock from underground, as opposed to a conveyor belt or ore bucket system, was based in part on the fact that the loaders and trucks from the open-pit mining operations were already available.

The kimberlite ore is processed in a large building on-site (figure 18) that is estimated to be 11 stories high and approximately 150 meters long and 40 meters wide. The ore first passes through a series of powerful magnets, which remove the unwanted pieces of steel mesh that are used to stabilize the tunnel walls. The ore is then crushed to progressively smaller pieces, removing the finer material. Diamonds are separated from the crushed ore by non-chemical, density-based methods to create a diamond-rich heavy-mineral concentrate (figure 19). Next, X-ray sorting uses fluorescence to recover diamonds from the concentrate. The processed ore material is then stored in a designated area on-site.

Although the diamond grade in the Diavik kimberlite pipes is very high compared to other primary mines, diamonds are still in very low concentrations overall, so a large amount of kimberlite ore must be

Figure 17. An ore hauler enters the access tunnel to reach the underground workings. Photo by James Shigley.

Figure 18. This view shows the ore processing plant (center), equipment repair shop (right), and office/dormitory complex (left). Photo by James Shigley.

Figure 19. The interior of the ore processing plant, where each step of the processing sequence to liberate the diamonds from the kimberlite ore takes place. Photo courtesy of Diavik Diamond Mine.

extracted and processed to recover them. As at other major mines, it is always surprising to hear that most workers have "never seen a diamond in the mine." Processing of the mixed kimberlite ore brought up from the workings of the A154 and A418 pipes involves a complex series of steps to create progressively smaller sizes to liberate the diamonds from the host rock (figures 20 and 21).

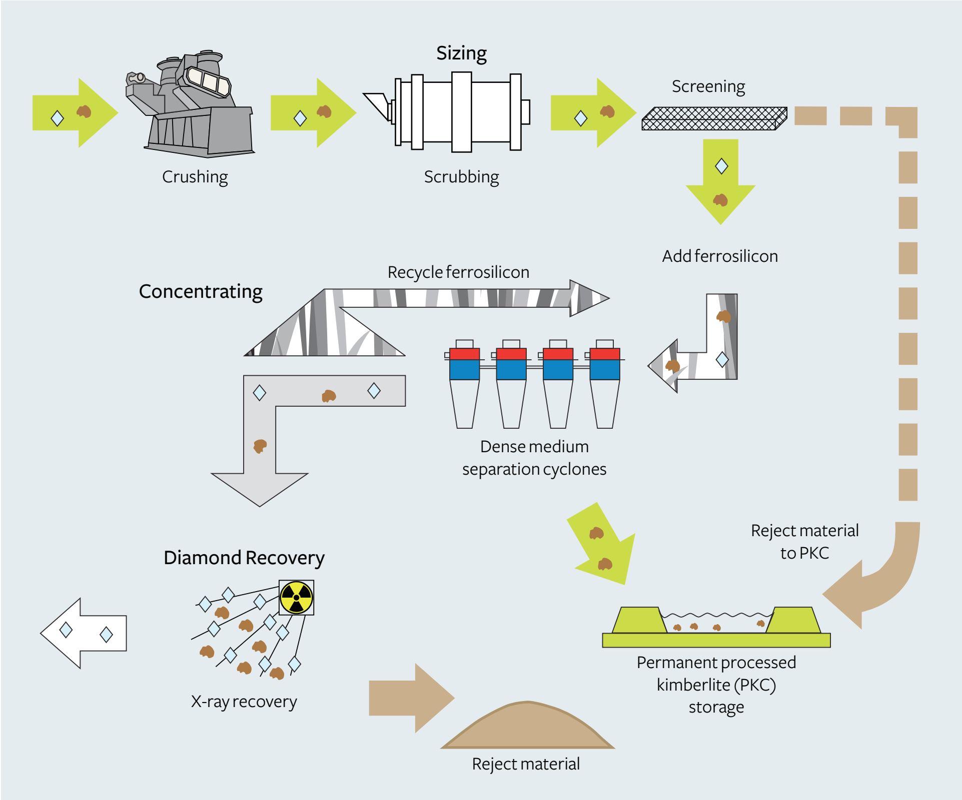


Figure 20. This diagram illustrates the steps in processing the bulk kimberlite ore to recover the diamonds. Courtesy of Diavik Diamond Mine.

Figure 21. The kimberlite ore is transported by conveyor belts between different stages of the processing sequence. Photo by James Shigley.

Grease tables are used to retrieve diamonds that cannot be efficiently recovered by X-ray fluorescence technology. Recovery of all diamonds takes place in a restricted area of the plant. Under stringent security, all diamonds are weighed, sorted, and documented before being packaged and flown to Yellowknife. At the product splitting facility, the rough diamonds are cleaned, sorted, and valued for government royalty purposes. The diamonds are separated by size for distribution to the two joint-venture partners, according to the production agreement. Once separated, the diamonds follow different paths for manufacturing and marketing.

Personnel. At the end of 2015, Diavik had approximately 1,000 employees, of whom 55% were from the Northwest Territories and 25% from the indigenous communities. Most employees work on a rotation, with two weeks of 12-hour shifts at the mine, followed by two weeks at home. Managerial staff work four days at the mine followed by three days off-site. Employee transportation to and from Yellowknife is provided by company or chartered aircraft. The mine operates around the clock every day of the year.

Safety. An extensive safety management system governs all aspects of mine operations. The system begins with training of all employees, safety standards for every area of activity, and regular reviews to continually monitor and improve safety practices. Before beginning any work activity, employees conduct a quick

Figure 22. Mine safety is paramount in the harsh winter climate of Diavik. Photo courtesy of Diavik Diamond Mine.

TABLE 1. Proven and probable kimberlite ore reserves at the Diavik mine, as of December 2015.

Pipe	Tonnes (millions)	Carats/tonne	Carats (millions)
A154N	8.8	2.4	20.8
A154S (underground)	1.5	3.3	5.1
A418 (underground)	4.6	3.6	16.7
A21 (future open pit)	3.7	2.7	10.0
Ore stockpile	0.1	3.5	0.3
Totals	**18.7**	**2.8**	**52.8**

Adapted from Diavik diamond mine: 2015 sustainable development report (2016).
Tables may not add up due to rounding.

safety check to identify and discuss potential hazards associated with the activity, as well as preventive measures that can be taken. The entire mine site is inspected regularly by outside agencies to ensure that all operations are conducted in a manner that protects and enhances worker safety and the environment.

Mine safety is particularly critical when operating in a harsh environment (figure 22). In winter, mining activities can be disrupted by whiteout conditions, where the lack of visibility causes spatial disorientation and can be life-threatening. These conditions occur about four times per year and typically last 8 to 12 hours. Weather monitoring is conducted to warn mine staff of whiteout conditions, as well as the onset of very low temperatures.

Production. With the exception of 2009, when demand was low due to the global financial crisis, annual production of rough diamonds at Diavik has consistently surpassed six million carats. As shown in table 1, Diavik's total mineral reserves at the end of 2015 were 18.7 million tonnes of unmined kimberlite ore containing an average of 2.8 carats of diamonds per tonne, for a total of 52.8 million carats of diamonds as proven or probable reserves. Table 2 presents annual production data from 2003 to 2014.

While the Diavik mine is not known for large diamonds, its kimberlite pipes contain exceptionally high grades (3–5 carats/tonne) of moderate- to high-value diamonds (compared to 0.5 to 1 carats/tonne in other locations). Production from the two operating pipes is valued well above the Kimberley Process average of US$116 per carat—$135 per carat for A154S and $175 per carat for A154N. The average value for A418 is $95 per carat (Dominion Diamonds, 2015).

Diamond crystals from the mine exhibit common forms such as octahedra, dodecahedra, macles, cubes, and aggregate shapes. Colorless crystals predominate, though brown and rarely yellow diamonds also occur; some others have a gray surface coating (Carlson et al., 1999).

CORPORATE SOCIAL RESPONSIBILITY

Relationship with Indigenous Communities. The 1991 diamond rush transformed the economy and society of the Northwest Territories. The subsequent development of several major diamond mines in this remote region transpired against the backdrop of a new relationship between the mine owners, the national government, and local communities. Over the past four decades, legislation, land claims, and legal challenges have strengthened the rights of Canada's indigenous communities over the land and water resources within their traditional territory. An important component of this power-sharing and cross-cultural governance over important land-use, environment, and wildlife decisions has been the increasing reliance on management boards with representation from the federal government, the mining companies, and local communities.

The company maintains a socioeconomic monitoring agreement with the territorial government, as well as environmental protection agreements with the indigenous communities and the federal and territorial governments. Councils involving the indigenous peoples have been consulted on a regular basis about mining operations since the discovery of the diamond occurrence in 1993. Discussions with these local groups have prompted revisions to the mine operation and closure plans, and this is expected to continue as long as the mine is in operation.

A representative body called the Traditional Knowledge Panel advises the company based on centuries of local habitation. For example, traditional understanding of wildlife habitats is being incorporated into the reclamation plan for revegetating the area. There was some discussion in this panel of how far to go in the revegetation process. While some people from the community believed that nature would "heal itself," most panel members understood that environmental disruptions from mine operations were more extensive than naturally occurring events, and that a more aggressive reclamation process was necessary (Diavik diamond mine reclamation review, 2007; Diavik diamond mine: 2014 sustainable development report, 2015).

As the mine was being developed, agreements were put into place to ensure that benefits would be

TABLE 2. Annual production of kimberlite ore and recovered diamonds from the Diavik mine, 2003–2014.

	Open pit			Underground			Total		
Year	Millions of tonnes	Millions of cts.	Cts. per tonne	Millions of tonnes	Millions of cts.	Cts. per tonne	Millions of tonnes	Millions of cts.	Cts. per tonne
2003	1.193	3.833	3.2	—	—	—	1.193	3.833	3.2
2004	1.950	7.575	3.9	—	—	—	1.950	7.575	3.9
2005	2.222	8.271	3.7	—	—	—	2.222	8.271	3.7
2006	2.331	9.829	4.2	—	—	—	2.331	9.829	4.2
2007	2.400	11.943	5.0	—	—	—	2.400	11.943	5.0
2008	2.414	9.225	3.8	—	—	—	2.414	9.225	3.8
2009	1.359	5.565	4.1	—	—	—	1.359	5.565	4.1
2010	1.765	5.625	3.2	0.326	0.875	2.7	2.091	6.500	3.1
2011	1.768	5.531	3.1	0.465	1.146	2.5	2.234	6.677	3.0
2012	1.116	4.006	3.6	0.942	3.224	3.4	2.058	7.230	3.5
2013	0.161	0.465	2.9	1.956	6.778	3.5	2.116	7.243	3.4
2014	—	—	—	2.277	7.233	3.2	2.277	7.233	3.2
Totals	18.68	71.867	3.8	5.966	19.256	3.2	24.646	91.122	3.7

Source: Yip and Thompson (2015)

made available to local indigenous communities. These included job training, employment at the mine, and opportunities for local businesses to provide needed services.

Environmental Monitoring and Protection. At Diavik, all mine activities are designed to protect the environment, anticipate potential problems, and meet regulatory requirements. A surveillance network is in place to monitor the water quality in and around the mine. In addition, the effects of mining operations on local wildlife (including caribou, wolverine, bear, and fish) and habitats (e.g., changes in vegetation) are checked on a regular basis. Efforts are made to minimize the production of dust from roadways and the airstrip.

Mine Closure and Reclamation. From the beginning of mine construction, plans were initiated to return the site to its nearly original condition once mining operations cease in 2024. Progressive reclamation of the site has been ongoing and is expected to cost US$131 million by 2030, once all the works have been removed from the site. A group of indigenous community representatives was organized to provide recommendations for the closure plan. They offered suggestions for revegetation and the creation of corridors for local wildlife such as caribou to pass through the mine site after closure. An important subject has been reclamation of the open pits to restore the original shoreline of Lac de Gras. The processed waste kimberlite ore will be sealed in a special containment area. All buildings and other facilities will be dismantled and removed, with the exception of the wind farm, which may be donated to provide electrical power to the community.

The final steps of the closure plan will be very complex. The waste piles must be shaped to match the natural landscape, which is relatively flat with occasional low hills and granite outcrops. The slopes of the piles must be stabilized to prevent them from giving way and endangering people or wildlife. Finally, the results of the reclamation project must have a neutral effect on the balance of nature in the environment. For example, the restored terrain should make it neither easier nor more difficult for migrating caribou to escape while being hunted by the indigenous peoples. Revegetation must not unduly attract caribou to the area or deter them from migrating through it (Diavik diamond mine reclamation review & cost estimate, 2007).

Even though Diavik was the second diamond mine to open near Lac de Gras, the joint venture faced considerable pressure from the local and federal governments, as well as environmentalists, to ensure the mine closure plan would return the land as closely as possible to its original state. This requirement came in response to the estimated 10,000 mining operations in the Canadian north that had closed with little or no reclamation plan, often posing physical or environmental hazards. For example, the Giant mine, a gold recovery operation near Yellowknife, closed in 1999, leaving 237,000 tonnes of toxic arsenic trioxide stored in the abandoned underground workings. Negotiations are still ongoing to decide on an appropriate clean-up plan and who should pay the cleanup costs ("Giant headache," 2014).

MARKETING OF DIAVIK DIAMONDS

The rough diamond sorting process is highly automated. After recovery, the diamonds are conveyed into a secured section of the plant where they enter sorting units—large metal canisters containing progressively smaller sieves down to 3 mm. At each sieve level, the diamonds are transferred into separate containers and packaged for shipment.

The Diavik mine is jointly owned by Diavik Diamond Mines Inc. (a wholly owned subsidiary of Rio Tinto plc) and Dominion Diamond Diavik Limited Partnership (a wholly owned subsidiary of Dominion Diamond Corporation). From the mine, the sorted diamonds are flown to a product splitting facility near the Yellowknife airport, where they are divided between the two owners—60% to Rio Tinto and 40% to Dominion Diamonds.

Rio Tinto. This Anglo-Australian mining conglomerate owns a 60% stake in the Diavik mine, which produced 6.7 million carats in fiscal year 2015. It also owns a 100% stake in Australia's Argyle diamond mine and sells that production in lots separate from Diavik. Rio Tinto markets all of its rough diamonds (figure 23) from a sales office in Antwerp, where it sold 70% of its four million carats from Diavik in 2015 at set prices to 17 "Select Diamantaires" who specialize in manufacturing and distributing Canadian rough and polished diamonds. These clients receive Diavik product via two-year supply contracts (Krawitz, 2015). Like De Beers, Rio Tinto schedules 10 sales, called "core sales," each year.

Five times per year, Rio Tinto also auctions key assortments from its production to engage with customers outside of its Select Diamantaire base. The company sells fancy-color diamonds and rough diamonds larger than 10.8 ct through two "Specials" tenders each year.

Rio Tinto, under its "Diamonds with a Story" platform, promotes Diavik's pure and clean Canadian origin and unique provenance. Downstream of the mine, Rio Tinto works in partnership with its Select Diamantaires to provide a tracking system, from the mine to the consumer, for Diavik diamonds (R. Ellison, pers. comm., 2016).

Figure 23. Rio Tinto markets its Diavik rough diamonds from a sales office in Antwerp. Photo courtesy of Rio Tinto Diamonds.

Dominion Diamond Corporation. Dominion Diamonds was originally the Canadian diamond exploration company Aber Resources, which discovered the Diavik site. Dominion owns 40% of the mine; the remainder is held by Rio Tinto, which developed the facility. Aber changed its name to Harry Winston Diamond Company in 2006 after acquiring the venerable jewelry retailer. In 2013, Harry Winston sold its retail division to Swatch, the Swiss-based luxury group, and became Dominion Diamond Company. The same year, the company acquired a majority share in the Ekati mine for $553 million. Dominion markets all of its Ekati and Diavik production separately.

In fiscal year 2015, Dominion sold 3.014 million carats of Diavik's production for US$351.6 million, averaging about $117 per carat. By the end of 2015, according to Dominion's annual report, the average per-carat price slipped to $105.

Dominion markets most of its Diavik and Ekati production through its sales offices in Antwerp. About 10% of its production is sold to clients in India ($30.4 million, against total sales of $351.6 million for fiscal year 2015). Initially, the mining companies in northern Canada set aside 10% of their production for local polishing operations (Krawitz, 2014). In 2008 there were six diamond polishing plants in Yellowknife, employing 150 workers ("Diamond cutting and polishing," 2008). By the following year, however, they all had closed, unable to compete with operations in India and China; this resulted in the loss of CAD$22 million in territorial government investments (Danylchuk, 2011). Attempts to revive a large cutting industry in Yellowknife have not succeeded, and currently there is only one cutting and polishing plant operating (Danylchuk, 2015).

Despite the demise of the local cutting industry, Dominion invested CAD$600,000 in 2015 in branding Diavik and Ekati diamonds by reviving the CanadaMark, a marketing program that was suspended after the local diamond operations closed. The CanadaMark brand is a mine-to-market custody chain designed to give diamond buyers the assurance that their purchases have been ethically sourced in Canada and processed by approved manufacturers. The diamond manufacturers selected to produce the CanadaMark come from the company's existing customer base in India and Israel, and they are continually audited to ensure sourcing and quality standards. Participating manufacturers offer the CanadaMark diamonds to retail clients who have signed up for the program.

Dominion targets the younger generation through various social media platforms and traditional advertising in print magazines. This age group is very concerned about ethical sourcing, so the chain-of-custody audit is necessary to provide this as well as the assurance that the diamond is truly Canadian.

Dominion hopes CanadaMark diamonds will eventually carry a premium over unbranded diamonds. The company's focus group research indicates that Canadian consumers will pay as much as 10% more, while buyers in the U.S. and Europe are willing to pay an additional 4% to 5%. Chinese buyers, however, noted they were unwilling to pay any premium based on country of origin (B. Bell and J. Pounds, pers. comms., 2015).

STUDIES OF THE DIAMONDS

Donnelly et al. (2007) presented results from a study of 100 inclusion-bearing Diavik diamonds that had been selected from more than 10,000 carats of "run of mine" production. They found that 83% of the diamonds were derived from peridotitic mantle source rocks, with Mg-chromite and olivine by far the most common mineral inclusions. Van Rythoven and Schulze (2009) examined inclusions and crystal morphology in a group of 110 Diavik diamonds. They also concluded that the majority were peridotitic, and that multiple growth and resorption events had affected diamonds from the A154 South pipe.

To further characterize the production from Diavik, in 2015 GIA acquired over 777 carats from Dominion Diamond. Of these, nearly 500 carats (326 samples) were gem-quality single-crystal diamonds, with the remainder consisting of bort, which was not part of this study. The 326 gem-quality rough diamonds ranged from 1.20 to 1.80 ct, and mainly included D-to-Z range (236), brown (70), yellow (3), gray (16), and pinkish (1) colors (figure 24). Several of the diamonds contained dark-colored inclusions that were assumed to be sulfides and other minerals (figure 25). Since both studies mentioned above were concerned with the inclusions in Diavik diamonds, we decided to focus our characterization on different aspects of the diamonds. Each of the 326 gem-quality diamonds was evaluated for crystal morphology, DiamondView fluorescence, and absorption spectra (FTIR and UV-Vis-NIR).

The Diavik rough diamonds examined were dominated by octahedral forms with varying amounts of resorption (figure 26). Of the 326 samples examined, 63% (206 diamonds) showed well-developed octahedral forms with little or no resorption toward the dodecahedral form. Twenty stones were very strongly resorbed to dodecahedral forms. Two showed cube forms, and 14 others appeared to be resorbed cubes that resulted in "hopper" forms. The shapes of 22 diamonds were dominated by twinning, with 17 of those being macles. Irregular forms were observed in 43 diamonds, and an additional 19 samples showed octahedral forms but had a complete or partial coating of light or dark fibrous diamond around a gem-quality interior (figure 27). Many of the rough octahedral diamonds without a coating showed strongly etched crystal surfaces, similar to those seen beneath the fibrous layer on the coated diamonds (where the coating was broken off), suggesting that a much larger proportion of Diavik rough diamonds was coated at one time.

Figure 24. Representative colors of Diavik rough diamonds, ranging from colorless to brown to yellow with one pink crystal. Also shown are several coated crystals. Photos by Jian Xin (Jae) Liao.

DiamondView imaging revealed uniform blue fluorescence in about 98% of the samples, varying in intensity from very weak to strong (figure 28). Only seven diamonds showed predominantly green fluorescence, all of which had resorbed cube-form "hopper" shapes. Three samples showed isolated patches of green fluorescence from the H3 optical defect oriented along crisscrossing linear planes within the dominant blue. The coated samples showed blue fluorescence in both the gemmy interior and the fibrous coating.

Figure 25. Several of the Diavik diamonds exhibited dark inclusions, presumably sulfide minerals. Photos by Jian Xin (Jae) Liao.

Infrared absorption spectra, collected using a Thermo Nicolet 6700 spectrometer with a diffuse reflectance accessory, revealed that all of the diamonds in this study contained nitrogen impurities and were type Ia. Total nitrogen content ranged from approximately 6 ppm to more than 1000 ppm, with only eight samples containing less than 100 ppm. Nearly 98% of the samples were either pure type IaA (dominated by A-aggregate nitrogen pairs) or mixed IaAB types with various proportions of A- and B-aggregates. Only eight (less than 3%) were pure type IaB (dominated by B-aggregate nitrogen groups), suggesting that the Diavik diamonds had not spent a long enough residence time at elevated temperatures within the earth for advanced nitrogen aggregation to occur (Allen and Evans, 1981).

UV-visible absorption spectra were collected at liquid nitrogen temperature using an Ocean Optics CCD spectrometer, integrating sphere, and halogen light source to evaluate the cause of color in the Diavik diamonds. Four UV-Vis spectral features were recorded: "cape" bands at 415 and 478 nm (causing pale yellow color), "vacancy cluster" general absorption increasing to shorter wavelengths (causing brown color), "550 nm" broad band absorption associated with plastic deformation (causes brown or pink color), and broad hydrogen-related bands at ap-

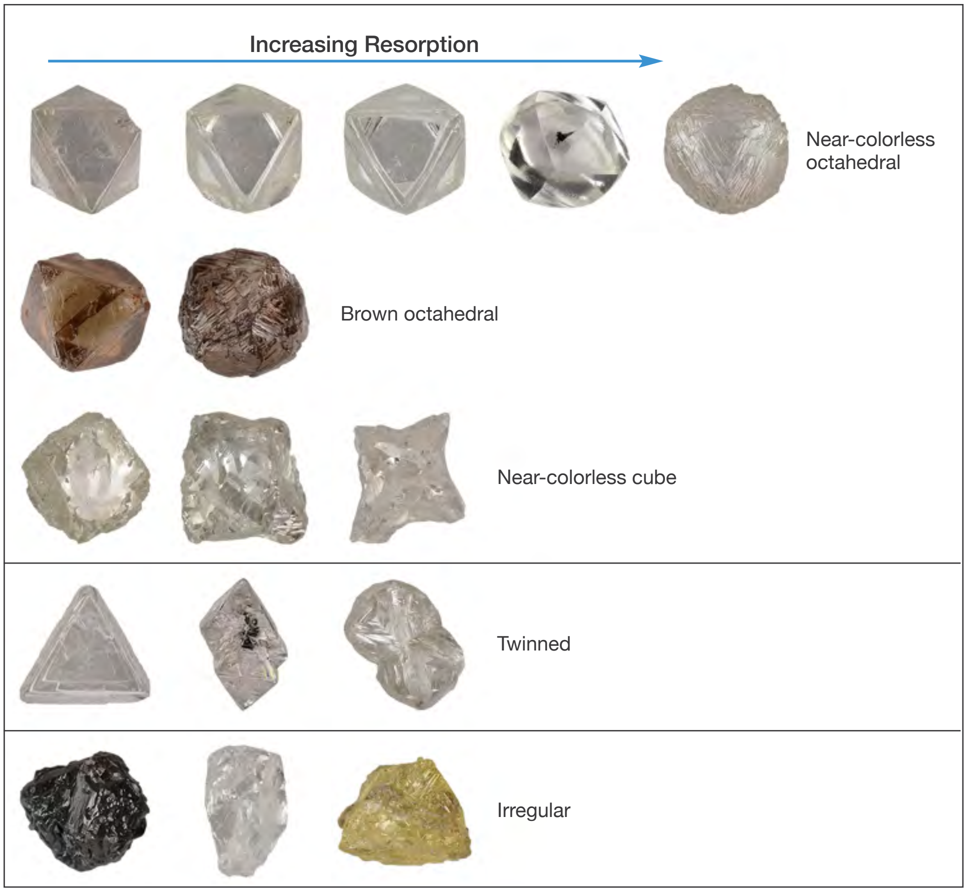


Figure 26. The morphology of the Diavik diamonds was dominated by octahedral forms that displayed varying amounts of resorption. Cube, twinned, and irregular forms were also present. Photos by Jian Xin (Jae) Liao.

Figure 27. Dark- and light-colored fibrous diamond coatings were observed on a few of the crystals. Photos by Jian Xin (Jae) Liao.

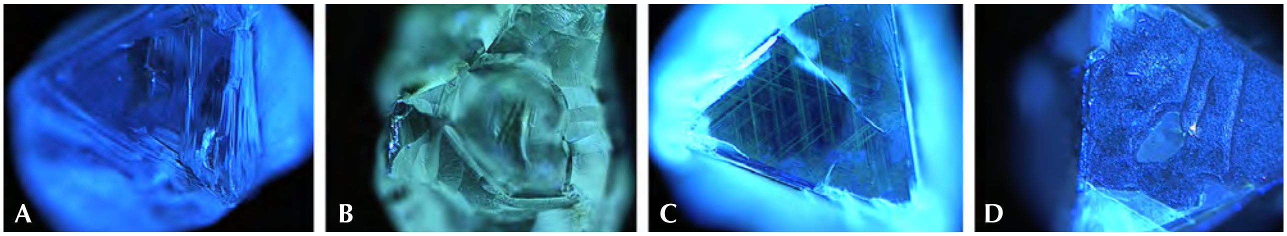
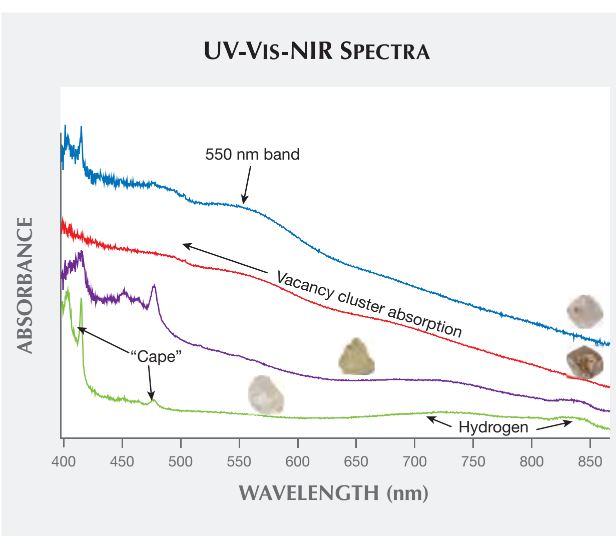


Figure 28. DiamondView imaging showed mostly uniform blue fluorescence (A). Seven "hopper"-form diamonds showed predominantly green fluorescence (B), and a few crystals showed green luminescence from H3 optical defects in linear patterns (C). Both fibrous coatings and interiors of coated diamonds (where parts of the coating are missing) fluoresced blue (D). Images by Kyaw Soe Moe.

proximately 720 and 840 nm (causes brownish or greenish color) (figure 29). Based on the spectra, ~58% of the rough diamonds have yellowish D-to-Z range or brighter yellow colors produced by "cape" bands with or without hydrogen features. With the exception of one pink diamond colored by a 550 nm band and 16 gray stones colored by coatings, the remaining samples were various shades of brown caused by a combination of vacancy cluster and 550 nm band absorptions. The presence of these latter absorption bands in ~37% of the samples suggests that a significant portion of the Diavik diamonds underwent plastic deformation, likely during kimberlite emplacement and eruption.

Figure 29. UV-Vis-NIR absorption spectra (offset for clarity) showed four features affecting the Diavik diamonds' color: absorptions due to cape bands, vacancy clusters, the 550 nm broad band, and hydrogen-related defects.



SUMMARY

Diavik is one of the world's most modern diamond mining operations. It is the largest diamond mine in Canada, producing approximately seven million carats per year, divided between the two owners. In June 2016, Diavik surpassed 100 million carats of production ("Diavik diamond mine: 2015 sustainable development report," 2016). Construction and operation of the mine presented considerable challenges because of Diavik's setting in an extremely remote

Figure 30. The superior quality of Diavik's production will ensure profitability through 2024. Photo courtesy of Rio Tinto Diamonds.

arctic area that can only be supplied for eight weeks a year via a temporary ice road. The kimberlite pipes are also located under lakes, requiring an elaborate system of dikes and drainage to maintain safe mining operations. While the mine is costly to run safely and sustainably, the high quality of the diamonds it produces (figure 30) will enable it to operate at a profit until its scheduled closing in 2024.

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For More on the Diavik Diamond Mine

To learn more about Canada's Diavik mine, visit www.gia.edu/gems-gemology/summer-2016-diamonds-canadian-arctic-diavik-mine, or scan the QR code on the right.

Fabergé Cossack Figures Created from Russian Gemstones

Timothy Adams and Christel Ludewig McCanless

Between 1908 and 1916, the workshops of the Russian court jeweler Carl Fabergé created approximately 50 hardstone figures representing the Russian people, including peasants, merchants, noblemen, and soldiers. Made from gems and precious metals, they are as rare as the well-known Imperial Easter eggs. The last Romanov emperor, Nicholas II, owned 21 of these portrait figures, two of which depict the Cossack bodyguards of the Romanov empresses. This article examines the hardstone figures through known biographical details, archival photographs of the Chamber Cossacks Kudinov and Pustynnikov, an original production sketch, and an invoice from the Fabergé firm. It discusses the creation of the pieces from gemstones and minerals mined in Russia.

To find a Fabergé piece lost in an attic for 79 years and sell it in less than 15 minutes for close to $6 million must be the ultimate thrill in auctioneering. The object in question was a carved hardstone replica of N.N. Pustynnikov, the personal bodyguard from 1894 to 1917 of Empress Alexandra Feodorovna (1872–1918). In a 2015 interview with the authors, Colin Stair of Stair Galleries described the rediscovery of the Fabergé figure in an attic in Rhinebeck, New York, and the October 2013 auction with one word: "Amazing!"

The story begins with the last Russian emperor, Nicholas II (b. 1868–1918), who was an avid collector of Fabergé hardstone carvings representing his subjects: peasants, merchants, noblemen, and soldiers. Records show that between 1908 and 1916 the Russian court jeweler Carl Fabergé (1846–1920) had commissions to create approximately 50 figures from various gem materials and precious metals (Adams 2014). These pieces are today as rare as the famous Imperial Easter eggs. Nicholas II owned 21 of them, including two with a special connection to the imperial family: a pair of Cossack[1] bodyguards who had served the Romanovs for many years (figure 1).

Since the time of Nicholas II's great-grandfather, Nicholas I, Russian emperors had assigned personal bodyguards to empresses and wives of heirs to the throne. Those appointed were Cossack noncommissioned officers from the emperor's own escort or other elite guard units. Known as Chamber Cossacks, they served not as soldiers but as "court servants of the first category." Their ceremonial dress, adapted from late 17th century Cossack and Russian attire, contrasted sharply with the Prussian-inspired livery of most other servants. As many as three Cossacks were assigned to an empress. They worked on a rotating basis, typically spending two weeks on duty and one week off. They were appointed for life and enjoyed privileges such as free lodging and health care. The Chamber Cossacks were mostly seen in public when an empress left her palace, occupying a seat of the royal carriage or automobile. They also accompanied her on trips outside of Russia.

The senior Chamber Cossack honored with a

See end of article for About the Authors and Acknowledgments.
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http://dx.doi.org/10.5741/GEMS.52.2.132

[1]Cossacks were from various ethnic and linguistic communities from the Caucasus Mountains, southern Russia, Ukraine, and Siberia. They served as bodyguards and mounted soldiers in the Imperial Army.

Figure 1. Left and right: The Fabergé hardstone figure of Chamber Cossacks A.A. Kudinov, who guarded Empress Maria Feodorovna from 1878 to 1915, and N.N. Pustynnikov, who served Empress Alexandra Feodorovna from 1894 until 1917. Photos courtesy of Pavlovsk State Museum and Gafifullin (2014) (left) and Wartski, London (right). Center: Archival photo of Kudinov and Pustynnikov in their ceremonial dress at annual military maneuvers presided over by Nicholas II in 1913 (www.sammler.ru/index.php?showtopic=140850).

Fabergé figure is A.A. Kudinov, who guarded Nicholas II's mother, Dowager Empress Maria Feodorovna (1847–1928). The 7.5 in. (19 cm) Kudinov piece was the 18th hardstone figure Nicholas II purchased from Fabergé. It was displayed in the Pavlovsk State Museum Collection (near St. Petersburg) from 1925 until 1941, and again after 1956. The recently rediscovered figure of Chamber Cossack N.N. Pustynnikov, also 7.5 in. tall, was purchased at the 2013 Stair Galleries auction by the British firm Wartski, a leading Fabergé dealer. Explored in this article are known biographical details and archival photographs of Kudinov and Pustynnikov, an extant Fabergé production sketch, and the use of Russian gem materials and precious metals in the figures.

In Brief

- In 1912, portraits of two Russian imperial bodyguards were created in stone by court jeweler Carl Fabergé.
- Historical background and archival photos of the Cossack guards Kudinov and Pustynnikov still exist.
- The gemstones used in these figures were mined in Russia, then carved and assembled by the Fabergé firm in St. Petersburg.

BIOGRAPHICAL DETAILS OF THE CHAMBER COSSACKS

Andrei Alexeevich Kudinov (1852–1915; figures 2 and 3) was born in the Cossack village of Medveditsa Razdorskaya in western Russia. He started his military service in 1871 and became a noncommissioned officer in 1876. He served in the Danube Army during the 1877–1878 Russo-Turkish War and was later appointed orderly and bodyguard to the heir, Grand Duke Alexander Alexandrovich (later Alexander III). In December 1878, he was assigned to Grand Duchess Maria Feodorovna, the wife of the future emperor; he stayed at this post when she became empress in 1881 and continued until his death. With his wife and three children, he lived at Anichkov Palace in St. Petersburg (The State Hermitage Museum, 2014).

Figure 2. Kudinov in his everyday dress, a dark blue kaftan. Photo courtesy of The State Hermitage Museum (2014).

Figure 3. Kudinov stands in front of the Emperor's Porch at Feodorovsky Cathedral in St. Petersburg in January 1914. This is probably one of the last photographs taken of him before his death in June 1915. Kudinov's and Pustynnikov's winter coats were identical except for the color of their belts (blue for Kudinov, red for Pustynnikov), which corresponded to the empress served. Photo courtesy of Central State Archives of Documentary Films, Photographs, and Sound Recordings of St. Petersburg, and The State Hermitage Museum (2014).

Kudinov's service record is kept in the Russian State Historical Archives in St. Petersburg. His career is also represented in the Fabergé figure by the engravings on the soles of his boots (figure 4) as well as the badges and medals on his neck and chest (figure 5). Around his neck, the Kudinov figure wears two large Medals for Zeal, the top one in gold from Nicholas II (awarded in 1906 for 30 years of service as a noncommissioned officer) and the lower one in silver from Alexander III (1893).

Nikolai Nikolaevich Pustynnikov (1857– after 1918; figures 6 and 7) was originally from the city of Novocherkassk, northeast of the Black Sea. Pustynnikov started his military service in 1876; he had a talent for music and in 1877 joined the regimental band as a trumpeter. In 1878, he was sent to St. Petersburg to join the band of the Guards Combined Cossack Regiment. Pustynnikov became a noncommissioned officer in 1881, and from 1884 to 1894 he was a trumpet major of His Majesty's Guards Cossack Regiment, even receiving a gold presentation watch from Alexander III for a solo performance. In

Figure 4. Kudinov's right boot is engraved with 1912 *on the heel and* A.A. Kudinov *in Cyrillic on the sole. His left boot is engraved with* Fabergé *on the heel and* Chamber Cossack Since 1878 *on the sole. Photo courtesy of Pavlovsk State Museum and Gafifullin (2014).*

Figure 5. Close-up of Kudinov's badges and medals. Photo courtesy of Pavlovsk State Museum and Gafifullin (2014).

December 1894, he was appointed by Nicholas II to guard Empress Alexandra Feodorovna. He served at Nicholas II's 1896 coronation and lived along with his wife and nine children in the servants' quarters at Tauride Palace and later at the Winter Palace (The State Hermitage Museum, 2014).

Figure 6. Pustynnikov escorts Empress Alexandra Feodorovna and three of her daughters on a horse-drawn sleigh. The photograph was taken by the Empress's sister, Princess Irène of Hesse, at the imperial residence in Tsarskoye Selo in 1908. The inset shows a close-up of Pustynnikov with Grand Duchess Olga. Photo © Hemmelmark Archives (Solodkoff, 1997).

Figure 7. The Empress, riding with the wife of French President Émile Loubet, arrives at Bétheny in 1901 for a review of the French Army. Pustynnikov is in the left rear seat of the carriage (red circle; from Les Fêtes de l'Alliance. 1901: Nicolas II et l'Armée Russe, Paris, *collection of Daniel Brière).*

Figure 9. Close-up of Pustynnikov's badges and medals. Photo © Wartski, London.

Pustynnikov's service is also reflected on his figure's boot engravings (figure 8), badges and medals (figure 9). Around his neck are two Medals for Zeal awarded by Nicholas II in 1902: the top one in gold on a ribbon of St. Stanislas and the silver medal below on a ribbon of St. Alexander Nevsky.

Figure 8. Pustynnikov's right boot is engraved with 1912 *on the heel and* Pustynnikov *on the sole. On his left boot, the heel is labeled* Fabergé *and the sole reads* Chamber Cossack Since 1894*. Photo © Wartski, London.*

THE WORLD OF CARL FABERGÉ

In August 1842, Gustav Fabergé (1814–1893) established a small jewelry business in St. Petersburg (figure 10, left) that lasted until 1918, when it was closed forever by the Bolsheviks following the Russian Revolution (Lowes and McCanless, 2001). Gustav's third son, Carl Fabergé, took over in 1872 (figure 10, right). With its amazing creations under his leadership, the firm was named Supplier to the Imperial Court in 1896. This began a long and fruitful relationship with the Romanovs. The firm supplied them with Easter eggs, presents for Christmases, birthdays, and name days, plus a variety of picture frames, presentation gifts, bell pushes, cigarette cases, cane handles, and hardstone animal and portrait figures. The House of Fabergé in St. Petersburg, along with its branches in Moscow (which specialized in silver), Kiev, Odessa, and a sales office in London from 1903 to 1917, catered to an elite clientele worldwide. Gems and minerals gathered across the Russian Empire were sent to the two main Fabergé production centers in St. Petersburg, with 500 employees, and Moscow, with 300 employees.

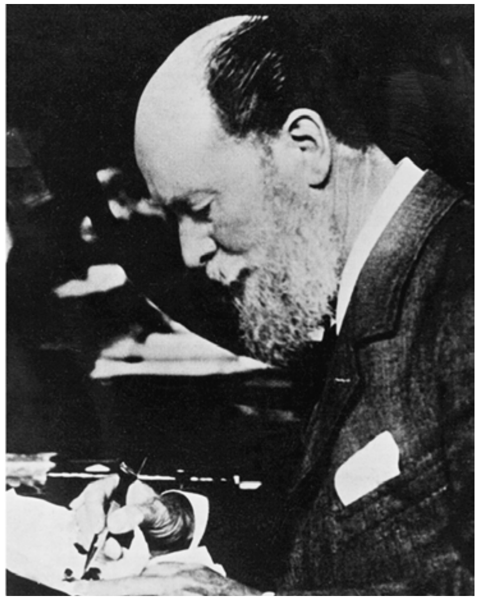

Figure 10. Left: Carl Fabergé's St. Petersburg retail shop and studios, with living quarters for his family on the top floor at 24 Bolshaya Morskaya ulitsa, ca. 1900. Right: Fabergé sorting stones, ca. 1890; archival photo by Hugo Öberg. Photos courtesy of Wartski, London.

By 1908 the lapidary workshop, located in the courtyard of a three-story building at 44 English Avenue in St. Petersburg, was equipped with 10 electric motors, 14 machines for processing stones, an emery wheel, and a kiln. At its peak, the workshop employed 30 expert craftsmen. By 1912–1914, the demand for hardstone animals as collectors' items would prompt Fabergé to increase its workforce and outsource work to stonecutters in Ekaterinburg, a city on the eastern side of the Ural Mountains (Muntian, 2005). But it was the craftsmen in St. Petersburg who transformed Russian gems and minerals into a variety of hardstone sculptures, including the two Chamber Cossacks commissioned by Nicholas II.

RUSSIA'S MAJOR MINING LOCATIONS

Fabergé had the natural resources of the Russian Empire at its fingertips. From beautiful pink rhodonite mined in the Ural Mountains to black obsidian and red-brown sard from the Caucasus Mountains and Siberian nephrite in rich shades of green, they were able to access the most varied and colorful gemstones for the jeweler's art. For centuries, Russia has also been a major source of precious metals such as gold, silver, and platinum.

Figure 11 shows the general locations of the gem and precious metal sources over the Russian Empire's 6.6 million square miles, as well as the route used by the Trans-Siberian Railway to transport the mining yield.

Chronology of the Two Chamber Cossack Figures

1912: Both figures are created by Fabergé and purchased by Nicholas II.

1918: After the Russian Revolution, the emperor's hardstone figures are traded by various dealers: Armand Hammer, Agathon Fabergé (second son of Carl Fabergé, 1876–1940), and Wartski, London. The Pustynnikov figure is brought to the United States for sale by Armand Hammer.

1925: The Kudinov figure goes on display at the Pavlovsk State Museum Collection until 1941.

December 11, 1934: Hammer Galleries in New York sells the Pustynnikov figure for $2,250 to Mrs. George H. Davis of Manhattan and Rhinebeck, New York.

1956: The Kudinov figure goes back on display at the Pavlovsk State Museum.

October 26, 2013: The Pustynnikov figure is offered for sale by the descendants of Betty Davis, the original American owner. The piece has remained in the family's hands since 1934 and has not been exhibited for 79 years. It is auctioned at the Stair Galleries in Hudson, New York.

Figure 11. Russia's important gem and precious metal sources are in the Caucasus Mountains, the Ural Mountains, the Altai Mountains, and Siberia. The route of the Trans-Siberian Railway is shown in red. The distance from the Altai Mountains to Moscow is approximately 3,000 miles (4,800 km), while Moscow and St. Petersburg are just over 400 miles apart.

Three large mountain ranges provided the majority of the stones for Fabergé. The Caucasus Mountains are made up of two parallel mountain ranges, the Greater and Lesser Caucasus, that extend from the northern shore of the Black Sea southeast to nearly the Caspian Sea. These mountains formed as a result of a tectonic collision between the Arabian and Eurasian plates. There is still volcanic activity, especially in the Lesser Caucasus, forming deposits of obsidian, a volcanic black glass used in stone carvings for its lustrous finish. Sard, calcite, garnet, amethyst, rutile, and quartzite are also found in the Caucasus.

Figure 12. Mining with hand tools in the Ural Mountains, 1910. Photo by chemist and photographer Sergey Prokudin-Gorsky, best known for his early 20th century pioneering work in color photography to document Russia and its people for Emperor Nicholas II. Source: Wikipedia.

The Ural Mountains, which form part of the boundary between Europe and Asia, extend more than 1,550 miles (2,500 km) from the northern border of Kazakhstan to the Arctic coast. The word *Ural* is thought to be of Turkish origin, meaning "stone belt." Russian mineralogist Ernst Karlovich Hofmann (1801–1871) explored this mountain range extensively beginning in 1828. Traveling thousands of miles, he collected gold, platinum, rutile, chrysoberyl, quartz, topaz, and other metals and minerals. The region became a virtual cornucopia of riches used in the thriving stone carving industry of Ekaterinburg. Malachite, amethyst, demantoid garnet, alexandrite, rhodonite, lapis lazuli, carnelian, sardonyx, and jasper mined with hand tools (figure 12) were carved into boxes, paperweights, and stone sculptures for a worldwide market.

The Altai Mountains and Siberia, with large diamond and nephrite deposits and vast resources of other gems and minerals, have supplied the jewelry trade for decades. Siberia makes up 77% of Russia's territory, extending east from the Ural Mountains to the borders of Mongolia, China, and Kazakhstan, and north to the Arctic Ocean and Bering Sea. On the southern border of Russia, the Altai Mountains are a source of aventurine quartz and gold. The Trans-Siberian Railway, constructed in stages from 1891 to

Figure 13. Pustynnikov's production sketch bears the internal Wigström workshop number 12995 with two completion dates. This suggests the two Chamber Cossack hardstone figures were created as a set, completed on January 31, 1912, and April 25, 1912 (Tillander-Godenhielm et al., 2000).

1916, linked the region to the rest of the Russian Empire and allowed greater access and use of these resources. Among colored gemstones, Siberian amethysts are known to be of the finest color. An imperial decree controlling the mining of Siberian green nephrite (highly prized for its rich color) increased that material's value. Since the 18th century, the Altai Mountains, which reportedly get their name from the Mongolian and Turkic word for gold, and the many gold-producing river basins in Siberia have made Russia a major supplier of gold. The Amur River region alone produced 96 tons from 1902 to 1915 (Habashi, 2011). Russia's important silver-producing regions are in the central and southern parts of the country. Major platinum deposits are in northern and eastern Siberia, near the Arctic Circle.

CREATING THE FABERGÉ CHAMBER COSSACKS

In 1912, Kudinov and Pustynnikov were asked to pose for Fabergé hardstone figures commissioned by Nicholas II. An existing watercolor production sketch of the Pustynnikov figure from Fabergé's third and last senior workmaster, Henrik Wigström (active 1903–1917), is shown in figure 13. Preliminary sketches guided the selection of colors and the pose of the figure. Next, a wax model was made to scale and proportion. Once the model was completed, it was sent to either the Fabergé lapidary workshop or the independent workshop of Karl Wörffel (figure 14), to be duplicated in polychrome gemstones carefully selected and matched for color and texture. Wörffel had one of the largest and finest stone cutting and

Figure 14. Karl Wörffel's independent bronze and lapidary workshop was acquired in 1915 by the Fabergé firm. Photo courtesy of Fabergé et al. (2012).

Figure 15. Russian gemstones used by Fabergé in 1912 to create the 7.5 in. (19 cm) portrait figure of Chamber Cossack Pustynnikov. Photo courtesy of Wartski, London.

bronze casting factories in St. Petersburg until his shop was acquired by Fabergé in 1915. His workshops served not only the Imperial Court but also clients in Germany, England, France, Belgium, and the United States. He supplied the House of Fabergé on a regular basis with hardstone animals, figures, flowers, and *objets d'art*. Wörffel's cutters also held a monopoly over Russia's nephrite supply, and had experience working with stones from the Caucasus, Ural, and Altai mountain ranges (Lowes and McCanless, 2001).

Each stone sent to the lapidary was cut to very precise measurements using both a cutting wheel and hand tools. Once the form and textures were perfectly carved, each piece of stone was brought to a smooth, lustrous finish on a polishing wheel. The pieces were assembled one at a time and joined with animal hide glue, before the final step of applying the gold and silver medals and trim. The variety of stones used in Pustynnikov's figure are detailed, from the most prominent to the smallest features, in figure 15 and in the text below.

Coat. The wool coat is carved from dark green nephrite. The realistic folds in the sleeves and the natural drape create a sense of movement and life. Independent Russian researcher Valentin Skurlov (2015) found that regardless of the variety of materials available, Fabergé's artisans preferred nephrite. In fact, the House of Fabergé in St. Petersburg was given special permission to keep four tons of the finest-quality nephrite, guaranteeing the craftsman always had ready access to this popular stone. The toughest of all natural stones, nephrite is opaque or translucent when cut very thin. The winter coat was trimmed with otter fur and a Romanov Imperial Eagle border. Fabergé replicated the fur with brown obsidian, and the double-headed eagle pattern of the border was fired onto metal strips and then applied as borders to the nephrite.

Pants, Boots, and Kiver (Hat). Without instruments to test gemological properties, one has to rely on visual clues. The items with a black fur texture (pants, boots, and kiver) are most likely chalcedony. Alternate black stones used in these figures could be jasper, onyx, jet, jade, or obsidian. The pants are trimmed in gold.

Kiver Bag and Belt. Hanging from the top right of each Cossack guard's kiver was a colored bag. The color of this bag and the belt worn around the waist corresponded to the empress served: blue lapis lazuli for Maria Feodorovna (Kudinov, see figures 16 and 17, left and center) and red purpurine for Alexandra Feodorovna (Pustynnikov; again, see figure 15). Purpurine, a deep crimson vitreous material brought about by the crystallization of lead chromate in a glass matrix, is the only synthetic material on either Cossack figure. Fabergé made great use of this material, especially in his animal figures.

Badges and Service Medals. Each Cossack's kiver features gold braid trimmings and a tassel of bullion fringe. Attached to the top left of the kiver is a Gold Badge of Office (seen in detail in figure 17, right) in the shape of a crowned escutcheon, with a gold monogram of the empress. The escutcheon is topped by ostrich feathers and surrounded by bullion braid to which removable rackets were suspended for ceremonial dress (The State Hermitage Museum, 2014). Pustynnikov's badge is missing from the Fabergé hardstone figure.

Figure 16. Chamber Cossack A.A. Kudinov's kiver bag and belt contain lapis lazuli mined in the Altai Mountains and Siberia. Photo courtesy of Pavlovsk State Museum and Gafifullin (2014).

Figure 17. Left: Kudinov, with a dark gray beard of Kalgan jasper, wearing a black chalcedony(?) kiver and the Gold Badge of Office. Photo courtesy of Pavlovsk State Museum and Gafifullin (2014). Center: This fur kiver with cloth bag, worn by Chamber Cossacks serving Dowager Empress Maria Feodorovna, was displayed at the 2014 "Servants of the Imperial Court" exhibition at the Hermitage Museum in St. Petersburg. Right: Extant Gold Badge of Office from the Kudinov figure, emblazoned with the monogram of Dowager Empress Maria Feodorovna. Center and right photos courtesy of The State Hermitage Museum (2014).

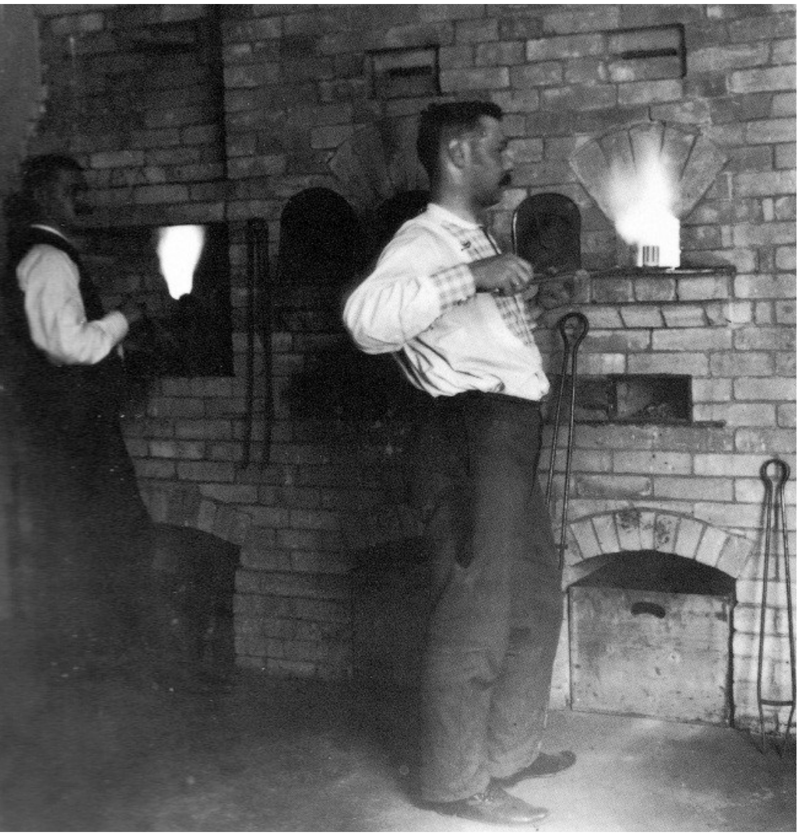

Figure 18. Fabergé's enamel firing furnace. Photo courtesy Wartski, London.

Service medals on the chest of the Fabergé figures are enameled, a process in which powdered glass is mixed with metal oxides fired at 600°–800°C (1300°F) to create a hard glossy finish in a variety of colors (figure 18). The delicately enameled medals applied to the nephrite coats of Kudinov and Pustynnikov are extremely small, yet remarkable for their accuracy (D. Brière, pers. comm., 2016).

Face and Hands. These features are carved from cachalong, a type of milky white to pale pink opal. It is easily carved, allowing the artist to give the face greater detail and personality and a more lifelike expression. Pustynnikov's attentive stare is in keeping with his duties as an imperial bodyguard. Cachalong is often mistaken for agate or chalcedony. Frequently misidentified in the Fabergé literature as a synthetic material, it has been used predominantly since 1913. Prior to that, the harder stone of aventurine was generally used to carve faces and hands in Fabergé's hardstone figures.

Beard and Hair. The two Cossack figures are similar but readily distinguished by their belt colors and by Kudinov's split beard. The beard and hair are made of gray jasper carefully detailed with a lifelike texture. Dark gray Kalgan jasper was used for Kudinov and gray jasper for Pustynnikov.

Eyes. The Cossacks' eyes glow with cabochon-cut blue sapphires from the southern Ural Mountains. Sapphires from this source were used in all but two of Fabergé's hardstone figures. When used *en cabochon*, cut and polished to a convex shape, the sapphire replicates the natural shape and eye color.

CONCLUSIONS

On an existing 1912 invoice from the House of Fabergé (figure 19) for the Kudinov figure, Nicholas II—not the Imperial Cabinet—is billed 2,300 rubles. It has been suggested the two Chamber Cossacks were by far the most expensive of the hardstone figures made. The cost of the original Kudinov, based on Benko (2015), equates to approximately $1,185 in 1912, and $28,200 in 2013. The Pustynnikov figure sold for nearly $6 million in 2013.

Fabergé scholar Alexander von Solodkoff (1988) noted, "The different parts were assembled so perfectly that the joints are invisible to the naked eye and frequently cannot even be detected with a needle." More than 20 of these hardstone figures have been sold through Wartski Jewelers in London since

Figure 19. The Kudinov invoice for 2,300 rubles, dated December 24, 1912, was paid from Nicholas II's personal account on February 12, 1913. Photo courtesy of Skurlov et al. (2009).

К. Фаберже — C. Fabergé

ПРИДВОРНЫЙ ЮВЕЛИРЪ — JOAILLIER DE LA COUR

СТ. ПЕТЕРБУРГЪ — ST. PETERSBOURG

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СЧЕТЪ

ЕГО ИМПЕРАТОРСКОМУ ВЕЛИЧЕСТВУ

ГОСУДАРЮ ИМПЕРАТОРУ

34

1912

декабря 24 фигура камеръ-казака Е.И.В. ГОСУДАРЫНИ ИМПЕРАТРИЦЫ МАРІИ ѲЕОДОРОВНЫ " Кудинова " " 2300.-

С.Петербургъ 12-го Февраля 1913.г.

the 1920s. In the words of the late A. Kenneth Snowman, Fabergé historian and proprietor of Wartski, Carl Fabergé had the

> unerring instinct for the right material, the meticulous treatment of detail, the vigorous sense of movement, and perhaps, above all, the obvious affection for and sympathy with the subject...Painstakingly carved pieces of stone of a suitable color and texture, each playing their appointed part, were carefully- and invisibly-fitted together. (Snowman, 1953, p. 65)

It is this attention to detail and precision craftsmanship for which Fabergé is famous. Even the most whimsical of his creations were designed with great care. His employees took pride in their work and were paid the highest wages in the industry. This attracted the best of the best to Fabergé. With access to the finest artists and the great gem and mineral wealth of Russia, Carl Fabergé built a lasting legacy of elegant perfection.

ABOUT THE AUTHORS

Mr. Adams is an independent art historian and Fabergé scholar who has worked in the fine jewelry industry for 30 years. A curatorial consultant and lecturer, he serves on Gems & Gemology's *editorial review board. Ms. McCanless is the editor of the quarterly* Fabergé Research Newsletter *(www.fabergeresearch.com). She is author of* Fabergé and His Works: An Annotated Bibliography of the First Century of His Art *(1994) and co-author of* Fabergé Eggs: A Retrospective Encyclopedia *(2001).*

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The Color of Responsibility: Ethical Issues and Solutions in Colored Gemstones

Jennifer-Lynn Archuleta

The mining and processing of colored stones, a multibillion-dollar industry, spans 47 countries on six continents. Despite the industry's high profile, an ethical, sustainable mine-to-market supply chain for these materials has still not been achieved, impacting the physical environment and quality of life for laborers. The history, issues, challenges, and efforts to rectify this lack of transparency and traceability are explored.

In addition to cut, color, and mounting, jewelry consumers have long been seduced by the "story" that accompanies their most treasured pieces. The history of a piece can provide romance and character to a purchase or gift. As a result, human rights and environmental issues related to the gem and jewelry industry supply chain are gaining attention among producers and customers worldwide. "Conflict diamonds" gained notoriety in the late 1990s (Global Witness, 1998), particularly after the 2006 release of the movie *Blood Diamond*. Yet diamonds are far from the only gem material requiring responsible sourcing. Due to its broad scope, the colored stone industry, estimated to be a US$10–$15 billion (and growing) global enterprise (Cross et al., 2010), has yet to establish a responsible, sustainable, verifiable mine-to-market supply chain (Responsible Ecosystems Sourcing Platform, 2016).

The mining and production of colored gemstones takes place in 47 countries (Boehm, 2014). Industry observers have noted that this sprawling and largely unregulated industry presents issues that are similar to other small-scale extractive industries: forced and child labor, other types of criminal activity, environmental damage, and health and safety concerns (Valerio, 2010; Cartier, 2010; Connell, 2014). They assert that these problems have been endemic in the colored stone industry, especially in artisanal small-scale mining (ASM) performed by individuals or small groups of people using rudimentary tools (figure 1). The concerns related to small-scale mining are pervasive with colored stones, 75%–80% of which are retrieved in this fashion (UNICRI, 2013).

As the United States' $78 billion jewelry industry continues to grow (Gassman, 2015), end customers are increasingly aware of the ethical impact of what they buy (Braunwart et al., 2015). As a result, more consumers are asking questions about the origins of pieces and basing their purchases on the answers they receive (Shor and Weldon, 2010). Millennials, the young adults born since the early 1980s, are the newest generation of gem and jewelry consumers. Studies show that this generation is particularly inclined to take factors such as fair trade status, sustainability, and human rights into account before making a purchase (Carter, 2014). As a generation, they consider their purchase a personal investment in a brand that represents their own values, and they are a force to be reckoned with: By 2020, millennials are expected to spend US$1.4 trillion annually on retail purchases (Young, 2014).

With these consumer interests developing alongside an environment of heightened scrutiny over responsible practices, both new and established colored stone suppliers are examining their relationships to the mining, cutting, and production sectors. Some industry leaders have long been concerned with corporate social responsibility, yet a combination of public awareness and the desire to self-govern the industry rather than be subjected to top-down legislation has been the greatest motivation to change. Governments

See end of article for About the Author and Acknowledgments.

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Figure 1. This view of the recently discovered ruby deposit in Zahamena National Park in Madagascar demonstrates conditions at a small-scale mining site. Photo by Vincent Pardieu/GIA.

and non-governmental organizations (NGOs) are feeling the impetus to create initiatives and voluntary standards that will foster social and environmental change within the entire industry—mining, cutting, trade, jewelry manufacture, and retail. As these standards take root, individual companies and organizations are launching community development and education efforts to improve the standard of living of miners, cutters, and their families.

As part of a panel on responsible practices at GIA in April 2015, Eric Braunwart, president and founder of colored gemstone wholesaler Columbia Gem House, noted, "I think we can come up with a new narrative, and that narrative is based around responsible sourcing, and helping everyone along the supply chain." This paper considers aspects of that supply chain in the context of current trends in corporate social responsibility (CSR) within the gem and jewelry industry. It also reviews some of the risks and challenges encountered by those endeavoring to ethically source colored gems.

BACKGROUND

Artisanal and Small-Scale Mining. Usually grouped together, artisanal and small-scale mining of precious metals, gem materials, and industrial minerals is conducted in more than 80 countries, on every continent except Antarctica (ASM-PACE, 2012). Traditionally, there has been no official definition of "artisanal mining"; the term was understood to mean the removal of material by individuals or groups using little to no mechanization. This type of mining often occurs where large-scale mining is illegal, physically inaccessible, or financially impractical. In 2013, the Organisation for Economic Co-operation and Development (OECD) published a definition of ASM pertaining to gold extraction (republished in 2016) that can easily be applied to other precious metals, minerals, and gemstones:

> Formal or informal mining operations with predominantly simplified forms of exploration, extraction, processing, and transportation. ASM is normally low capital intensive and uses high labour intensive technology. "ASM" can include men and women working on an individual basis as well as those working in family groups, in partnership, or as members of cooperatives or other types of legal associations and enterprises involving hundreds or even thousands of miners. For example, it is common for work groups of 4–10 individuals, sometimes in family units, to share tasks at one single point of mineral extraction (e.g. excavating one tunnel). At the organisational level, groups of 30–300 miners are common, extracting jointly one mineral deposit (e.g. working in different tunnels), and sometimes sharing processing facilities (OECD, 2016c).

Figure 2. Alluvial mining often involves the retrieval, washing, and sorting of gem materials from gravels, as with this processed tsavorite from Lemshuko, Tanzania. Photo by Robert Weldon/GIA.

ASM is a form of subsistence mining that can quickly generate income. This is especially true for alluvial mining, where stones and gravels from riverbeds are sifted for gems (figure 2). The material is generally close to the surface, allowing for easy retrieval. Agricultural workers seeking work outside of a given farming season often supplement their income through alluvial mining.

ASM is particularly widespread in developing countries, which often have high illiteracy rates (B. Wheat, pers. comm., 2015). According to the Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development (2013), across the entire mining industry, which encompasses both minerals and precious metals, there are approximately 30 million artisanal miners worldwide, including about 2 million children. There is, however, no reliable figure for the number of people involved in small-scale colored stone mining. A 2007 report from the International Labour Organization (ILO) notes that colored stone extraction is often a family affair, with school-aged children of both genders participating in sifting and sorting.

The Rising Popularity of Colored Gemstones. Colored gemstones were especially popular prior to the mid-20th century; it was not until after the Great Depression and World War II that diamonds took center stage in engagement and wedding jewelry (Matsangou, 2015). Efforts by De Beers, which formed in 1888, to create an air of romance and rarity around diamonds began to catch on in 1947 with the iconic "A Diamond Is Forever" campaign (Sullivan, 2013).

In recent years, colored stones have seen a resurgence. This enthusiasm is due in large part to greater access to material from remote areas, as well as the stronger advertising and promotion of these gems (R. Shor, pers. comm., 2015). This promotion largely results from the efforts of multinational companies such as London-based Gemfields, which has invested heavily in marketing and promotional campaigns. Gemfields has accomplished this through various channels, from signing Hollywood actress Mila Kunis to a three-year contract to represent their brand (Carr, 2013) to partnering with designers to create collections from their responsibly sourced production (King, 2016). Their efforts dovetailed with the overproduction and subsequent weak demand for diamonds (Boehm, 2014). With this greater availability and marketability, more designers are turning to colored stones. This has allowed jewelry consumers to purchase pieces that offer a distinctive look for less money (R. Shor, pers. comm., 2015). The rise in colored stone popularity coincides with the industry's recent attempts to improve the lives of the miners and cutters who are the very foundation of the trade.

Corporate Social Responsibility vs. Fair Trade. While there is an impulse to use the terms "corporate social responsibility" (CSR) and "fair trade" interchangeably, the two have distinct meanings.

According to Visser (2008), CSR encompasses "the formal and informal ways in which business makes a contribution to improving the governance, social, ethical, labour and environmental conditions of the developing countries in which they operate, while remaining sensitive to prevailing religious, historical and cultural contexts." Simply put, it is a company-led commitment, worked into its business plan or mission, to safeguard social values, community relations, and the environment. The CSR movement has gained traction among many industries since its inception in the 1960s. Sustainable development, the preservation of natural resources for future generations, is usually a central tenet of CSR. This is often mistaken for philanthropy and designated as a public relations effort rather than the core mission of a business (Nieuwenkamp, 2016). CSR involves responsible sourcing and due diligence from corporations who create policies for their own work and also influence their business partners to do the same to ensure a "clean" supply chain (see box A).

In Brief

- The colored stone industry, worth US$10–15 billion and largely driven by artisanal and small-scale mining (ASM), has yet to establish a sustainable, ethical mine-to-market supply chain.
- Challenges include remote mining sites, cost, poor relations along the supply chain, and "greenwashing."
- Intergovernmental organizations and NGOs have created frameworks for gem mining and other sectors that can mitigate environmental impact, prevent human rights abuses, build relationships with miners and cutters, and meet community needs.

Fair trade, a post–World War II social movement that has its origins in missionary programs and political and humanitarian groups (Fair Trade Federation, 2011), seeks to alleviate the poverty and marginalization of producers who have traditionally been excluded from the benefits of mainstream business. Secondarily, it creates a relationship between disadvantaged producers (in the case of ASM activity, mine workers) and consumers by following set guidelines for production, sourcing, and manufacturing, creating expectations among end-customers. The fair trade movement also focuses on raising awareness about trade imbalances and abuses of power, while creating policies that promote equitable trade (World Fair Trade Organization, n.d.). Several different organizations exist to certify a product and designate it a "fair trade" item; issuing organizations have guidelines and audits that lead to certification and permission to use the fair trade designation. For instance, Fairtrade International has a list of standards pertaining to pricing, trade, hired labor, and prohibited materials (among others) that must be met before they will issue their logo to a producer (Fairtrade International, 2011). While a company may include CSR goals as part of their mission, this does not mean their products will be issued fair trade certification.

Many of the colored gemstones currently in circulation would not qualify as "fair trade" for one simple reason: time in the marketplace. Cartier and Pardieu (2012) compared the number of privately owned gems (both in museums and private collections) against up-to-date production numbers and estimated that many were decades old. Since established frameworks only address current mining practices and provenance, many of the gems on the market cannot be designated "fair trade," even if they were produced in the past using the appropriate practices (Cartier and Pardieu, 2012); however, such designations may be applied in the future by modifying existing guidelines.

THE ISSUES

While media attention has caused some people to associate diamonds with horrific human rights abuses, smuggling, and terrorist funding, colored stones are not immune to criminal activity. Actions taken to create positive change in the colored gems sector are discussed in the "Responsible Solutions and Recommendations" section.

Forced and Child Labor. Forced labor, though universally condemned and illegal, is an unfortunate reality of gem mining. Forced labor is defined by the ILO as "all work or service which is exacted from any person

Box A: Applying Due Diligence to the Gem and Jewelry Supply Chain

One concept at the core of a sustainable and traceable supply chain is due diligence, a risk management strategy a company uses to evaluate an individual, company, or product ("Due diligence…", 2015). Within the gem and jewelry sector, the risks that require due diligence include child and forced labor; living conditions; health and safety risks; environmental impact; ties to armed conflict, terrorism, and known criminal activity; money laundering; and smuggling ("Due diligence…", 2015). For instance, a jeweler who wished to create conflict-free pieces would perform due diligence to ensure her gold supplier did not source material that was mined via forced labor. Current legislation, regulations, and nongovernmental organization (NGO) frameworks have been influenced by intergovernmental institutions such as the International Labour Organization (ILO), the United Nations (UN), and the Organisation for Economic Co-operation and Development (OECD). The following timeline demonstrates each organization's role in achieving current standards.

1919: As part of the Treaty of Versailles at the end to World War I, the International Labour Organization (ILO) is created as an agency of the League of Nations. The ILO is dedicated to promoting social justice and internationally recognized human and labor rights by developing labor standards that address production, security, and human dignity.

1945: The United Nations (UN) is founded, replacing the League of Nations.

1946: The ILO becomes an agency of the UN.

1948: The Organisation for European Economic Cooperation (OEEC) is created to help administer the post–World War II Marshall Plan.

The Universal Declaration of Human Rights, which sets out fundamental rights such as the prohibition of slavery, equal pay for equal work, and freedom of movement, is adopted by the UN. It is the first document to spell out these fundamental rights, and is the basis of many subsequent frameworks and laws.

1961: The OEEC expands beyond Europe, becoming the Organisation for Economic Co-operation and Development (OECD).

1976: *The OECD Guidelines for Multinational Enterprises (MNE)*, outlining sustainable development recommendations to rely on economic, environmental, and social progress, is published. The *MNE* is updated in 1979, 1984, 1991, 2000, and 2011.

1999: The ILO publishes *Social and Labor Issues in Small-Scale Mines*.

2000: The UN Global Compact (UNGC), the world's largest corporate sustainability initiative, is formed.

2005: The Responsible Jewellery Council (RJC), a third-party certification organization, is founded by 14 industry members.

2010: In the United States, the Dodd-Frank Wall Street Reform and Consumer Protection Act (Dodd-Frank), with provisions governing disclosure on conflict minerals (tin, tantalum, tungsten, gold, and their derivatives) from the Democratic Republic of Congo region, is signed into law.

2011: Publication of the *UN Guiding Principles on Business and Human Rights*.

The first edition of the *OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas* (*OECD Due Diligence Guidance*) is published. The document is the basis of a variety of initiatives, including the RJC's Chain of Custody Certification, the ITRI Supply Chain Initiative, Solutions for Hope, and the World Gold Council's Conflict-Free Gold Standard.

2012: The U.S. Securities and Exchange Commission names the *OECD Due Diligence Guidance* as a framework for companies who must file a conflict minerals report under the Dodd-Frank Act.

under the menace of any penalty and for which the said person has not offered himself voluntarily." For instance, a mine operator could threaten a worker or his loved ones, retain his identification documents, or deprive him of food or sleep. A worker's living quarters might be kept under surveillance or isolated from the community. Debt bondage, wherein wages are withheld or loans must be paid through labor, is another method of coercion. An employer might also seek to exploit a worker's vulnerability by taking advantage of illiteracy or forcing female workers into prostitution (Hidrón and Koepke, 2014).

Child labor is any form of work detrimental to a child's general well-being, including their education and their physical, emotional, and mental health. Not all labor activities involving children are considered harmful; in fact, a child or adolescent's "participation in work that does not affect their health and personal development or interfere with their education, is generally regarded as being something positive" (United Nations, n.d.). This is frequently the case when an entire family is involved in mining colored stones. In Kambove, Democratic Republic of Congo (DRC), many children had to be at the mineral mining sites because their families could not pay for schooling costs. Some children worked more hours during school vacations, and at least one child reported that his wages paid part of his school fees (World Vision, 2013). Other children were kept onsite due to lack of childcare options. In light of this, allowing children to work at mining sites benefits the family and community at large (World Vision, 2013).

Even so, the mining industry is considered by the ILO to be hazardous to children (2011). While ASM or alluvial mining might not seem particularly harmful, it is often the result of coercion or debt bondage between an employer and the child's parents or other family members (United Nations, n.d.). Thus, the psychological hold over both child and parent is devastating. The International Programme on the Elimination of Child Labour (IPEC), administered by the ILO, indicated that in addition to health and safety risks, informally run mining areas are notorious for a culture of drug abuse, prostitution, and violence (2006). The physical demands of the work also have a negative effect on children's well-being (see "Health and Safety Concerns").

Forced labor and child labor arise not only in colored stone mining, but also in cutting and processing (Leber, 2010; Martinez Cantera, 2014). Materials known by the U.S. Department of Labor to be produced by exploitation are listed in table 1.

TABLE 1. Colored stones mined and processed by forced and child labor.

Material	Forced Labor	Child Labor
Emerald	Colombia	
Jade	Myanmar (Burma)	Myanmar (Burma)
Ruby	Myanmar (Burma)	Myanmar (Burma)
Sapphire	Madagascar	
Tanzanite	Tanzania	
Multiple	Bangladesh, India, Zambia	

Adapted from the U.S. Department of Labor (2014).

Other Forms of Criminal Activity. Over the past 15 years, diamonds have come under a great deal of scrutiny for financing guerrilla and terrorist groups. Colored stones also have a troubling background as a method of funding criminal activity.

Burmese rubies and jade may be the most notorious among colored gems for funding conflict and perpetuating other human rights atrocities, but they are not alone. During their rise to power, the Khmer Rouge famously mined sapphires from the Cambodian province of Pailin in order to fund guerrilla activities. After the fall of Phnom Penh in 1975, sapphires continued to finance the regime. By 1979, when the Khmer Rouge was overthrown, Cambodian sapphire had been mined into near nonexistence ("Pailin blue sapphire," 2014). More recently, a prosecution witness linked the tanzanite trade to the August 1998 bombings of U.S. embassies in Dar es Salaam, Tanzania and Nairobi, Kenya (Maharaj, 2002). This allegation supported the post-9/11 claim that al-Qaeda had ties to the tanzanite trade, though the U.S. State Department would largely dismiss such a connection (Schroeder, 2010).

The value of colored stones to a country or regime should not be underestimated. Global Witness (2015) estimated that the Burmese jade industry alone was worth about US$31 billion in 2014. More recently, Afghan lapis lazuli (figure 3) has come under scrutiny for financing conflict. Global Witness reported in May 2016 that material from Badakhshan province has been funding insurgents and other armed groups since 2014. Production from the area raised approximately US$12 million for armed groups in 2015, with an estimated US$4 million of lapis mine revenue paid to the Taliban (Global Witness, 2016). Illegal contracts and intimidation have kept money in the pockets of these groups and out of the pockets of locals with mining rights, as well as the official Afghan government, which in 2014 lost US$18.1 million in revenue from the two mining districts of Deodarra and Kuran wa Munjan (Global Witness, 2016). While President Ashraf Ghani announced efforts to deal with the crisis, as of this writing there were no measures taken to monitor or retake control of mining sites, and illegal extraction and smuggling of lapis continue. As a result, Global Witness has named Afghan lapis lazuli a conflict mineral (Global Witness, 2016).

Colored stone mining is also susceptible to other types of criminal activity. Emerald and corundum have been vehicles at various times for fraud, smuggling, and money laundering (Naylor, 2010). Because of their small size and a lack of oversight and regulation, colored gems are easily smuggled. One notable case is Zambia; an estimated $60 million worth of emeralds are smuggled out of that country every year (Hill, 2013).

Environmental Impact of Colored Stone Mining. The environmental damage caused by mining precious metals is well documented. The use of mercury and cyanide in gold extraction is harmful to plant and animal life. Virtually all gold mining results in rock and soil erosion, deforestation, and sulfuric acid pollution in air and water (Bland, 2014).

Colored gemstone mining is generally less hazardous to the environment than gold mining because chemicals are not used. Furthermore, digging for colored gems generally takes place within 10 meters of the earth's surface (Valerio, 2016b). Still, there remains considerable uncertainty regarding the environmental impact of colored stone production. When asked about gemstone mining's carbon footprint[1] on the environment, British jeweler and industry activist Greg Valerio said this was a common yet unresolved question among ethical jewelers, one that deserved answers, particularly from large-scale operations (Valerio, 2016b).

Even so, gemstone mining is known to have harmful effects. Unless proper, sustainable practices–including land reclamation and rehabilitation–are part of the mining plan, soil erosion and degradation, deforestation, and harm to plant and animal life are inevitable. Negative impacts on the environment can include habitat loss, spread of disease to animal species, population decline of critically threatened or endangered species, increased human/wildlife conflict, decline in water quality, and destruction of land and aquatic ecosystems (ASM-PACE 2012).

Figure 3. In June 2016, lapis lazuli from Afghanistan was named a conflict mineral by Global Witness. Photo by Duncan Pay.

Health and Safety Concerns. The health impact of gem production and processing on laborers is significant. For independent miners, the lack of appropriate sanitation facilities can result in illnesses and diseases. Abandoned diggings may become filled with stagnant water that attracts mosquitoes, leading to the spread of malaria (ASM-PACE, 2012), and causes waterborne diseases such as dysentery (Hilson, 2002). Pools of water left unattended are also a drowning hazard, particularly among children in the surrounding areas (ASM-PACE, 2012). Meanwhile, the round-the-clock nature of mining can cause sleep deprivation, appetite loss, and fatigue (Hilson, 2002).

The toll on human health does not end with gem extraction (figure 4). The Solidarity Center, a global labor organization, estimates that 80% of all colored stones in the market are processed in cutters' homes or in small shops (Connell, 2014). Eric Braunwart warned that "there are probably many more people dying in our industry from the cutting end than the mining end" (pers. comm, 2015). These workers frequently contract deadly lung diseases such as silicosis as a direct result of gem cutting. An estimated 30% of all gemstone grinders will die of silicosis (Na-

[1] A simple definition of "carbon footprint" is the tons of carbon dioxide (or CO_2 equivalent) produced by one's actions, either directly or indirectly, per year.

Figure 4. Cobbing and cutting gem materials without appropriate ventilation or safety gear, such as the surgical mask worn by this woman at the Anahí ametrine mine in Bolivia, can lead to silicosis and other respiratory illnesses. Photo by Robert Weldon/GIA.

tional Labor Committee, 2010). While silicosis is most closely associated with cutting, the disease may also be contracted by workers in underground mines, as with tanzanite miners in Merelani, Tanzania (Cartier, 2010). Headaches, impaired vision, and fatigue may also result from gemstone cutting; asphyxiation may even occur. Children in the workforce suffer orthopedic problems such as bone deformation, and skin conditions are another area of concern (World Vision, 2013).

CHALLENGES

Once the issues have been identified, the impediments to resolving those issues must be recognized. Each colored stone type comes with its own unique set of circumstances, and a commitment to sustainable practices calls for patience, steady financial resources, and an understanding of the local community's culture.

The first problem is the sheer number of small-scale mining sites. With so many of them scattered in remote areas around the world, monitoring each one is not a realistic solution. There are, in fact, no recorded estimates for most colored stone mining sites, making it extremely difficult to trace the exportation of stones from these areas. Any effort at total oversight without taking into account rush activity, which appears and disappears virtually overnight, is impossible. Even if it were realistic, the expense of such an enterprise could be prohibitive for many smaller businesses who would otherwise be interested in consistently tracing exportation, though some models exist in other extractive industries (see "Regulations and Frameworks" section). Eric Braunwart of Columbia Gem House sees financing as a major roadblock; while interest in fair trade gems and sustainability has grown over the past decade, many small businesses were derailed by the global financial crisis that started in 2007. The crisis and subsequent recession damaged the mining industry at large, and colored stones were no exception. Mining, already curtailed due to high fuel costs, came to a standstill in many locations, with production and retail sales following suit (Shor and Weldon, 2010). Because it can take years to see results from mining activity, sustainable practices were now beyond the reach of many small gem dealers and jewelry manufacturers (E. Braunwart, pers. comm., 2015). Greg Valerio (2013) indicated that he had to reduce staff, close workshops, and deplete his own savings on several occasions to successfully create a line of ethical jewelry.

In addition, there is a level of distrust between producers and buyers. Small-scale miners are accustomed to being taken advantage of. These relationships "have never been based on a mutual profitability, mutual respect and support model" (E. Braunwart, pers. comm., 2015). Some of this comes from not understanding local cultures and traditions. Another factor is the miners' lack of gemological and pricing knowledge. The high illiteracy rate among artisanal miners leaves them unequipped to fully understand their own product, and thus they are easily swindled out of a fair market price (Weldon, 2008). This continues the vicious cycle of poverty.

Public perception also comes into play, especially with the previously noted misunderstanding of the differences between "fair trade" and "sustainable." While many people are aware of the general concepts of fair trade, the movement actually encompasses an entire spectrum of actions, whereas ethical business practices in the gem industry have primarily focused on traceable chains of custody rather than sustainable actions (Hilson, 2014). When questions regarding fair trade practices are asked by jewelry customers, especially millennials well versed in the fair trade movement, answers that pertain only to traceability may be less than satisfying.

Ideas about CSR and its role across industries are also changing. As previously mentioned, CSR is often seen as voluntary philanthropy, and the work of company CSR managers is all too often considered tangential to daily operations (Nieuwenkamp, 2016). This attitude of neglect toward CSR works to a company's detriment. A 2015 survey of more than 2,500 companies reported that nearly one out of five were subject to CSR-related sanctions amounting to about 95.5 billion euros (roughly equivalent to US$108 billion) between 2012 and 2013 (Nieuwenkamp, 2015). This is leading some in the business world to believe that, in the words of Townsend (2016a), "Corporate Social Responsibility is, at best, only a partial solution—one which can be misused to create an illusion of responsibility." Thus, many key players are rethinking their approach to the topic (see "Meeting Community Needs" section below).

While many consumers do believe in the importance of an ethical gemstone supply chain, a number of skeptics consider this movement "greenwashing," an environmentalist-inspired marketing scheme to get consumers—in this case, jewelry customers—to pay top dollar for an ultimately meaningless designation. In fact, some industry members and the general public feel that the industry is not doing nearly enough to address the issues faced by miners and processors and have lost heart about the colored stone industry's motivation and capacity to change. Greg Valerio believes the movement has lost ground over the past ten years, although not because the industry lacks commitment. To him the problem is that the same industry movers are talking to each other rather than to the consumer (Valerio, 2016a). This insularity, which Valerio refers to as a "cul-de-sac of inertia," keeps the movement from gaining momentum.

RESPONSIBLE SOLUTIONS AND RECOMMENDATIONS

Although there is no "one-size-fits-all" solution due to geographic, political, and socioeconomic differences between gem-producing areas, most experts agree that simply boycotting jewelry is not a solution. The miners who eke out a living by small-scale mining would ultimately suffer. Nor is the solution to cut out buyers altogether. Thomas Cushman of the Gemmological Institute of Madagascar, points out that every role along the supply chain is necessary for it to function, as mining and dealing require different skill sets, an assertion confirmed by the United States Agency for International Development (2011). Rather than eliminate the market or the players, the essential components are managing human rights abuses alongside instances of white-collar crime (OECD, 2016c), providing reasonable payment for services, establishing and maintaining a minimum hiring age, championing environmental rehabilitation and reclamation, and instituting strict health and safety standards (Alawdeen, 2015). On the cutting side, fair labor hours and safe working conditions are also necessary. Various parties have launched efforts to improve these issues within the colored stone mining sector.

Regulations and Frameworks. The general public is broadly aware of the measures intended to prevent "conflict diamonds" from financing rebel groups and militias. As of this writing, 52 countries around the world voluntarily meet the minimum requirements of the Kimberley Process Certification Scheme, established by the UN General Assembly in 2003. Significantly, the Kimberley Process extends only to rough diamonds being used to fund rebel militia efforts to overthrow a legitimate government, not to other human rights issues. There are currently no binding international regulations with regard to colored stone trade, even in a limited scope.

Some governments have taken steps toward colored stone regulation. In the United States, the

Burmese Freedom and Democracy Act of 2003 banned the importation of all products from Myanmar (formerly Burma). Congress expanded this order in July 2008 through the Tom Lantos Block Burmese Junta's Anti-Democratic Efforts (JADE) Act, which specifically prohibited imports of rubies and jadeite from Myanmar (figure 5), as well as products incorporating these items. In August 2013, President Barack Obama issued an executive order to reinstate the import ban, which had expired in July of that year. The reinstatement applied it solely to gemstones; the other elements of the ban had already been lifted. As of May 2016, the ban on Burmese jade and rubies remains in place (Pennington, 2016).

The *UN Guiding Principles on Business and Human Rights* (UNGP), endorsed in 2011, serves as a framework for creating international standards. The UNGP holds that both states and corporations have a duty to prevent and remedy human rights abuses. Further, the UN's Global Compact, formed in 2000, established 10 principles for sustainable business practices; to date, the Global Compact has more than 8,000 business-related and 4,000 nonbusiness participants, including NGOs, labor unions, academic institutions, and cities/municipalities ("Who should join?", n.d.).

Intergovernmental organizations are not the only actors on the ethical jewelry scene. Independent groups have formed to help ensure transparency and promote fair treatment of workers. The Responsible Jewellery Council (RJC), a third-party certification organization, goes a step further than the UNGP. The RJC subjects its more than 700 voluntary member companies ("Members," n.d.) to additional standards that have been guided by the Compact and other sources, and then has those efforts audited by independent third parties. RJC members must receive certification within two years of joining, submit to voluntary third-party audits, and make ongoing efforts to improve their business practices ("FAQs: Membership & membership responsibilities," 2012). Certified members can then pursue Chain of Custody Certification, a framework that was inspired by the OECD's *Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas*. Following this guidance indicates that all materials used are ethically produced along the entire supply chain—that they meet human rights, labor, environmental impact, and accepted business standards. Yet the RJC has faced criticism that loopholes in their system allow members to use jewelry materials that do not meet ethical

Figure 5. The Tom Lantos Block Burmese JADE Act, an act of Congress signed in 2008, banned ruby and jadeite imports from Myanmar into the United States. Photo by Robert Weldon/GIA.

standards with regard to forced and child labor, environmental protection, or certification process, among other issues ("More shine than substance…", 2013). Moreover, the RJC's Chain of Custody Certification is only available for diamonds and precious metals, although in March 2016 RJC announced plans to expand its scope to include colored stones ("RJC to expand scope...," 2016).

In the wake of the Dodd-Frank Act of 2010 (again, see box A), tracking and tracing systems for conflict minerals from the DRC region have been implemented, such as the one developed for Miniema province (Channel Research for iTSCi, 2012). Similar systems could be created for the colored stones sector. The Jeweltree Foundation, a Netherlands-based non-profit, uses an online track-and-trace platform for its supply chain. Founded in 2008 to give small-scale miners a voice in the international market while certifying ethical, traceable jewelry lines, Jeweltree works directly with cooperatives and small-scale communities in Brazil, Madagascar, and Tanzania. To set up a viable track-and-trace chain, Jeweltree has set up a database wherein certified members (or supporters) are listed and their actions to assemble jewelry are logged. Jeweltree has a list of suppliers of metals, gems, and services that have been approved by the organization as ethical and transparent. Each step of the process, from selection to final polishing, is logged in their database (Jeweltree Foundation, n.d.).

Since 2013, governments and groups representing the industry, including the International Colored Gemstone Association (ICA), have worked with the United Nations Interregional Crime and Justice Research Institute (UNICRI) to create a system for tracing and certifying colored gemstones origin (Chen, 2013). More information on this program will be available later in 2016.

Education. Without question, promoting education for colored stone miners and processers will improve their quality of life (S. Pool, pers. comm., 2015). In many areas where ASM is practiced, high illiteracy rates make it difficult to implement safety regulations or value stones appropriately (B. Wheat, pers. comm., 2015). Providing literacy education allows the miners to interpret and follow protocols that protect both themselves and the environment; it also allows them to access employment options outside of mining. Another practical option is to provide training at the literacy levels of the workers themselves, a method that has been successful in some areas, including South Africa (Booyens, 2013).

Keeping the production local through value-added activities such as cutting, setting, and design is another vast undertaking that may have long-term benefits. These activities create new options that build upon the existing economy of a gem-producing area. The Bridges family keeps the cutting of their tsavorite production in Kenya, near the Scorpion mine, and plans to do so for the foreseeable future (Hsu and Lucas, 2016). The Gemmological Institute of Madagascar, founded in 2003, teaches gemology, gem cutting, and fashion jewelry design and creation; there is also a gem lab on-site (T. Cushman, pers. comm., 2015). This allows the Malagasy people to gain valuable trade knowledge about the materials found on their native soil.

Meeting Community Needs. Recognizing the need for responsible and sustainable practices, many companies are making the move to vertical integration, the merging of two or more businesses that operate at different stages of the production chain ("Vertical integration," 2009). When one company has control over various aspects of production and manufacturing, this structure allows producers to maintain a more transparent mine-to-market trail and to more efficiently contend with the risks that go along with those trails. The concept of a carefully monitored supply chain has been pursued and practiced by some industry innovators since the turn of the century. A secondary benefit of vertical integration is that a company charged with both mining and cutting gem material has a chance to develop relationships with the people who perform these duties.

There have been efforts to meet the needs of mining communities through CSR. Weldon (2008) noted that some Colombian emerald mine owners were working with local governments to build roads, schools, hospitals, and homes, which improved quality of life and resulted in greater efficiency and production. Founded in 1977, Columbia Gem House has been at the forefront of responsible sourcing for over a decade. At GIA's April 2015 panel, the company's president and CEO Eric Braunwart discussed Columbia's creation of the Dzonze District Development Fund in Malawi. This group, made up of locals, provides feedback to Columbia on the community's most pressing needs. One outgrowth was the construction of a school that, due to the high percentage of adults with AIDS in the area, has also provided residence for orphaned children. Building this school has helped identify the need for more teachers, more housing for those teachers, clothing for schoolchildren, sewage facilities, and other infrastructure to meet the needs of the locals and the new population of teachers.

Some analysts, in an effort to recognize the importance of ethics and sustainability in a company's operations, are moving away from CSR to embrace the concept of responsible business practices (RBP). CSR has a reputation for "feel-good" projects and, as previously mentioned, carries a connotation of philanthropy and voluntary compliance (Nieuwenkamp, 2016). The reimagined RBP is intended to create a strong, productive business based on high sustainability and strong social and environmental practices, integrated not only throughout the supply chain, but also into every aspect of the corporate culture (Nieuwenkamp, 2015; Townsend, 2016b).

All speakers at GIA's April 2015 panel on responsible business practices confirmed that ethical sourcing is an ever-evolving process wherein they must identify new areas for economic and community development. In the past, such efforts have included building hospitals and schools (figure 6); future RBP efforts must involve maintaining medical staff and teachers at these facilities, along with updated equip-

Figure 6. Children attend the school built in 2007 by Swala Gem Traders in Arusha, Tanzania. Photo by Robert Weldon/GIA.

ment and other resources. There are opportunities available for those who wish to make a difference in the world of colored stones. Beth Gerstein of U.S.-based jewelry retailer Brilliant Earth noted that her company has provided scholarships in conjunction with the Gemmological Institute of Madagascar and plans to work with community development efforts in the colored stones field in the future (B. Gerstein, pers. comm., 2016).

While creating long-term plans to start their own socially responsible foundation, UK-based Nineteen48 supports several charitable efforts in Sri Lanka, including Emerge Global's Beads-to-Business program ("Programs and impact," 2016). This project teaches Sri Lankan women leadership skills and business knowledge, alongside jewelry design, to help them achieve long-term self-sufficiency ("Programs & impact," 2015). And in June 2016, the American Gem Trade Association (AGTA), in conjunction with the ICA and the Indian Diamond and Colorstone Association (IDCA), announced a study to evaluate how to address silicosis in the colored stone industry (Branstrator, 2016). These programs are setting the stage for future generations of industry leaders. Mr. Braunwart reiterated that young people entering the industry will be setting these standards, both in the gem industry and in the business world at large, in the years to come.

Relationship Building. Understanding indigenous cultures and building trust with artisanal miners and their community leaders can lead to ethical sourcing while generating a steady supply of gemstones. Recognizing that each region has its own culture, and that CSR and RBP should be sensitive to established traditions, is key to a successful relationship. Fostering these relationships and respecting the community's identity may also discourage miners from selling the stones for ultimately illegal purposes. Gem dealer Guy Clutterbuck has developed relationships with small-scale African miners and independent cutters based on respect for tradition and trust. In an interview on ethically sourcing aquamarine, spessartine, and tourmaline, Clutterbuck explained his working relationship with the chief and two representatives of the Tombuka (or Tumbuka) tribe, which stretches from Zambia into Mozambique and Malawi. His practices, which include paying in advance for rough and allowing the material to be collected, set aside, and retrieved by him later, have a "trickle-down" effect on the local economy, as the tribal chief makes sure his people benefit from these purchases (Choyt, n.d.). This is quite different from the tribe's earlier dealings with buyers. Clutterbuck also noted that he uses a cutter in Sri Lanka who subsidizes education and food costs for employees and their children (Choyt, n.d.).

Involving the miners and cutters in the community development process will also generate goodwill and underscore the workers' importance to the entire operation. There can be no responsible sourcing and production without these essential local personnel, a fact that should be driven home to everyone along the supply chain. Allowing these community members to identify their own needs and see them brought to fruition, as Columbia Gem House has done in Malawi, instills the confidence necessary to continue doing business with trustworthy buyers, and allows those same community members greater financial security in the future.

While a "one-size-fits-all" approach will not accommodate every aspect of the jewelry supply chain, there are lessons to be learned from previous endeavors in other sectors. In a feasibility study on the direct marketing of Liberian and Central African–mined diamonds, USAID indicated that some of their findings would be relevant for non-diamond-related supply chains, including colored gemstones (2011). While reiterating that the most successful strategies are those that directly involve the miners, the authors advised that any formalization project requires the following:

- *Trust, transparency, and partnership*: Taking the time to develop relationships, offering fair market value for mined material, and making workers feel instrumental to the success of the operation are key factors.
- *Certainty of price, volume, and delivery of supply*: Since the volume of gemstones collected by artisanal means can vary, it may be best to take a grassroots approach, partnering smaller jewelers with lower demand to mine sites.
- *Keeping the middlemen*: While there is often a desire to eliminate gem buyers, they do in fact perform a variety of commercial duties, as noted by Thomas Cushman. Buyers provide the financial liquidity that keeps a mine operational ("Due diligence…," 2015). In addition to entering the market on behalf of the miners who would otherwise be looking for gems, middlemen also provide sorting and transportation of material, freeing the miners from these tasks.
- *Understanding the artisanal miner's mindset and existing marketing strategies*: It is key to understand why the miner is motivated to sell.
- *Basing plans on existing structures and institutions as much as possible*: Understanding the way local political systems work and adapting the mining operation accordingly is more likely to be successful than imposing structures that may be foreign, or even repugnant, to the culture.
- *Starting with producers who have demonstrated commercial and/or development success*: All players should demonstrate the ability to perform his or her given task, from producing gems to marketing the material to creating community development opportunities (USAID, 2011).

Reclamation, Remediation, and Recycling. Land reclamation uses practical methods to restore land to productive use, while remediation is specifically the removal or reduction of hazardous wastes or materials to protect the environment. Both play important roles in sustainable gemstone production. Reclamation may include restoring topsoil or planting native plants such as trees or grasses in the previously mined area, while remediation plans can involve the reduction or elimination of heavy metals from the soil or drinking water. Small and artisanal mining operations often do not recognize the importance of these measures; even when they do, they seldom have the financial resources to put such efforts into practice (Cartier, 2010).

Cartier and Pardieu (2012) have called upon the trade to become more involved in reclamation and remediation, rather than relying on the miners or governments to act. They maintain that the multi-billion-dollar industry can afford to set aside an optional levy of 0.1% at a retail level for conservation and remediation purposes. Their article also suggests holding gemstone auctions to support regional projects, such as the sale of tsavorite to fund conservation projects at the Tsavo national parks in Kenya.

Recognizing the financial burden of reclamation and rehabilitation, the Asia Foundation's Frugal Rehabilitation Methodology (FRM) recommends a course of action that is achievable for ASM communities (2016a). FRM is designed to be funded by governments or large-scale mining interests who wish to address degraded and abandoned mining sites, but the Whole Mine Cycle Approach, another element of FRM, is a way for small mines to incorporate the methodology into their standard operations in order to mitigate, rather than retroactively repair, the effects of mining (Asia Foundation, 2016a). FRM includes defining the boundaries of the area to be rehabilitated, providing a plan for waste management and disposal of toxic waste, accounting for the amount and types of infill material and topsoil needed, and scheduling the planting of appropriate vegetation. Since 2014, 17 projects using FRM have been successfully completed (Asia Foundation, 2016a), with one such project launched in Mongolia in April of this year (2016b). While FRM was developed specifically for gold and fluorite mining sites, it would serve well as a model for rehabilitating colored gemstone sources.

In addition to remediation efforts, some companies are reaping the benefits of recycled materials already in the market. Most of the gold mined throughout recorded history, an estimated 165,000 metric tons, is still in circulation (Bland, 2014). Since 2007, U.S.-based jewelry manufacturer and refiner Hoover and Strong has supplied 100% recycled precious metals, including gold, to the industry, moving away from the mining process as part of their efforts to "go green" (S. Grice, pers. comm., 2016). This has been a very realistic and successful approach for Hoover and Strong. The company is also pursuing and promoting responsibly mined gold on behalf of the companies they do business with, though the additional costs of sourcing the metal have made this difficult. With this enterprise, there is also the concern that "dirty gold" is being laundered through supply chains (Sharife, 2016), although there are frameworks in place for precious metals that diligent businesses can follow to prevent this from happening.

Consumer Education. Jewelry has always been an emotional purchase, and customers care about the "story" behind their pieces. Eric Braunwart stressed the "emotional value of gemstones to the consumer," noting that stones with a backstory are preferred over those of unidentified origin. Millennials, who have grown up knowledgeable about fair-trade products and sustainability, expect that issues pertaining to human rights, environmental impact, and social consciousness are addressed in the supply chain for the products they wish to purchase (Bates, 2016). Members of the GIA panel confirmed that the "silent majority" may not ask for clarification or proof of ethical, sustainable material, but in the end they expect it. Since many companies have long-established practices and are generating healthy revenues without following responsible practices, they may be reluctant to change. Thus, the general public must be prepared to ask questions about the origin of materials and demand detailed answers from manufacturers or dealers (S. Pool, pers. comm., 2015). Jewelry activist Marc Choyt (2013) adds that if just 5% of jewelry customers insisted on ethical products from retailers, the impact on the worldwide industry would be dramatic.

Consumer education is vital to the success of this effort. Openness about the supply chain, including the mines of origin, the buying process, and manufacturing details educates the public and ensures long-term consumer confidence. There are various ways of assuring the public, such as marketing materials that provide details about the mines and communities in which the stones are sourced. In April 2016, Greg Valerio's blog featured a video interview with a member of a gold co-op in Uganda who explained how Fair Trade gold has improved their lives. Such videos could also be used to explain how community development helps colored stone mining areas. These kinds of efforts, along with training retail staff about the importance of the ethical and sustainable background of the pieces they are selling, create greater public awareness. Certain responsibly mined products do carry a higher cost (about 10%–15%, according to Gerstein), so explaining the value of that designation may be useful to the consumer.

CONCLUSIONS

As gem and jewelry consumers become increasingly conscious of responsible practices, they are demanding greater transparency from the companies who provide their goods. The gem and jewelry industry has felt this pressure and is starting to change. Despite the inherent financial, logistical, and communication challenges, a growing number of trade members are adopting practices that will improve the livelihoods of workers and protect the environment; this in turn has the potential to create more long-term sustainability. Domestic and international trade regulations and membership organizations that require responsible practices create the impetus for these companies to maintain a higher ethical standard. Acknowledging and managing the impact of mining and production on human quality of life and the environment at large promotes community development, education, and responsible future sourcing.

The level of transparency exhibited by producers who make ethical and sustainable decisions regarding their products and practices creates a chain of responsibility that benefits miners, cutters, and other industry laborers. Public disclosure of these efforts and subsequent improvements lead to greater consumer trust and ultimately greater demand, especially among the millennial population that has come to expect such behavior in the marketplace.

Adopting responsible business practices can increase the volume of ethically sourced materials, while improving quality of life among ASM personnel, ensuring greater trust among producers and buyers and sustaining the mining and cutting trades around the world. Yet the very real financial and logistical challenges cannot be underestimated. Major efforts to educate consumers about these challenges and their obvious and subtle impacts alike may be the key to unlocking the next wave of ethical practices. It is important to reach this broader audience to combat consumer and industry fatigue. Reaching out to the public will help spread the message Fashion Revolution cofounder Orsola del Castro delivered in April 2016: "I don't want to wear someone's misery, I want to wear someone's dignity" (Valerio, 2016c).

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Jennifer-Lynn Archuleta is the editor of Gems & Gemology.

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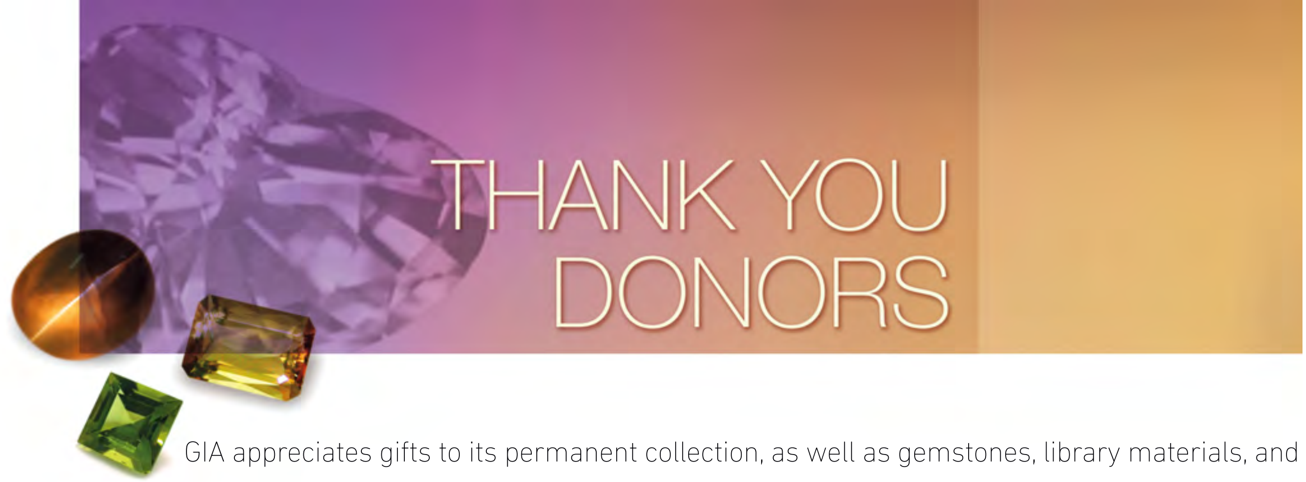

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The Challenges of Cutting a Large Gem Opal Rough

Theodore Grussing

Cutting large gem-quality opal rough poses special challenges not encountered when working with smaller pieces. The author explains the considerations in cutting a 3,019 ct piece of gem-quality white opal that was mined from the Olympic Field in Coober Pedy, South Australia, during the 1950s. Through careful analysis and planning, he was able to extract a single finished gem weighing 1,040 ct, with play-of-color across the entire surface. Named the Molly Stone, it is one of the largest fine gem opals ever cut. This article describes the unique factors involved in maximizing its size and play-of-color.

Opal has long been considered one of the most beautiful gemstones in the world, as it displays all the colors of the visible spectrum and each gem is unique. With faceted gemstones, the cutter lays in a pattern of facets at precisely calibrated angles, transforming the rough from a transparent pebble into a brilliant gem. With opal, the beauty is often hidden within the stone, and it is the cutter's skill that determines whether this beauty is exposed or lost. With faceted gems, mistakes can often be corrected. But with opal, the moment you make the wrong cut the beauty is lost forever, and the stone becomes an ugly gray piece of silica.

Sometime during the 1950s, miners recovered an enormous piece of seam opal from the Olympic Field in Coober Pedy, South Australia. The decision was made to "face" the stone, which is simply taking it to the lap wheel and grinding a colorless overlying potch layer down to the color bar to see if there is a strong, uniform play-of-color underneath (figures 1 and 2). I have worked with many pieces of opal rough where the color bars have shown brilliant play-of-color when viewed from the side but faint, ghost-like colors when viewed from the top. In that case, the best option is to cut small stones using the side of the color bar as the top, maximizing the richness of color. Figure 3 shows where a small nip was taken from the top, exposing the second large color bar.

Whoever mined and faced this rough opal decided to let someone else take the risk of further work on it. At some point the 3,019 ct piece was sold to Lawrence H. Conklin, a noted dealer and collector in New York. After the opal passed through several more hands, I had the good fortune to purchase it in 2014. Based on my 40 years of experience cutting thousands of opals (see Grussing, 1982), I decided to undertake the unique challenge of cutting this large gemstone while documenting the decision-making process and the techniques for the benefit of other lapidarists and gem enthusiasts. I spent innumerable

Figure 1. The faced top and sides of the rough specimen, showing multiple gem-quality color bars. Photo by Robert Weldon/GIA.

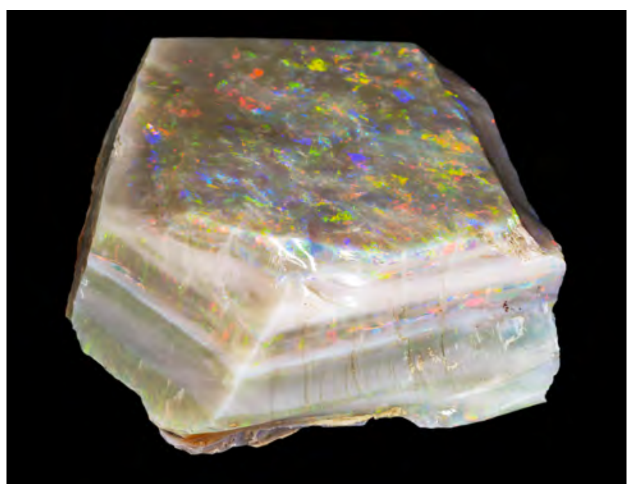

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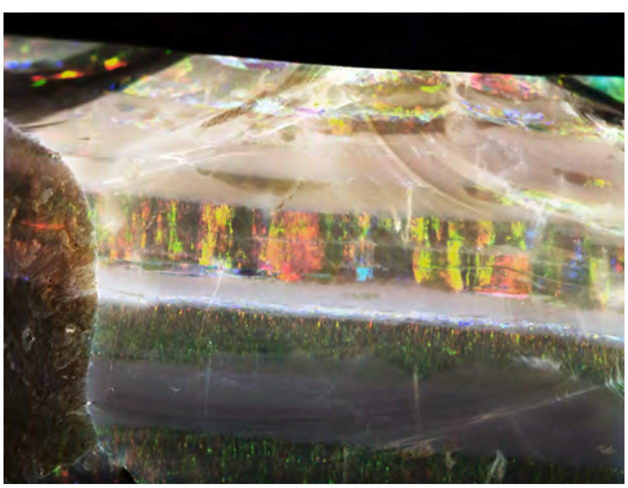
Figure 2. A side view shows all the color bars and intervening layers of colorless potch. Photo by Robert Weldon/GIA.

hours over many months looking at the rough under different lighting conditions, considering all the possibilities before I began to map the cuts.

EXAMINATION AND EVALUATION

In this specimen, there are multiple layers of silica gel from which the opal has formed. Some of these layers or bars are precious opal, and others are common opal with no play of color (potch). The thickness and color quality of these bars vary throughout the stone. The color bars seemed relatively consistent, but there was the distinct possibility that they undulated and varied in thickness, perhaps narrowing down or even disappearing. The opal's top surface displayed full and intense color from every angle and in any lighting. The remainder of the piece had four more thick color bars separated by layers of potch; at least three of these color bars appeared to have very strong play-of-color (again, see figure 1).

Figure 3. A close-up view from a different side of the opal displaying an extraordinary color bar. Photo by Robert Weldon/GIA.



There were a few conchoidal fractures on the edges extending into the top color bar on the surface. These occurred during the mining process or when someone later nipped it. Two of the sides still had the original skin, which left a thin layer of potch over the color bars. The question was how thick the bars were and how strong the color was beneath the skin. A few very small areas on the top appeared to be slightly "sand shot," with sand embedded in the silica gel. I wondered how these areas could be removed without going through the top color bar, which appeared to be about 2 mm thick.

There were three options for the rough:

Leaving the 3,019 ct Opal Intact. Leaving the piece of rough intact would retain the mystery of the opal and the element of wonder as to what gems it might produce. Though it was a beautiful, very large example of gem-quality opal in its natural state, this was the least attractive option commercially. Besides, I already knew the stone in this form, and it is not in my nature to simply do nothing: There was a stone to explore and a risk to be taken. For me, leaving it alone was not an option.

In Brief

- After purchasing a 3,019 ct rough opal mined in Coober Pedy, Australia, the author decided to cut a single museum-quality specimen weighing more than 1,000 ct.
- The primary challenge was leaving the top color bar intact while retaining as much weight as possible.
- After countless hours spent mapping the stone, the author shaped it using a series of increasingly fine cutting wheels, making slight adjustments along the way.
- The resulting 1,040 ct opal, named the Molly Stone, displays play-of-color from nearly every side and from every angle.

Cutting Individual Gems or Matching Suites for Jewelry Use. Cutting the rough for jewelry pieces would maximize the value of the gem material. I estimated it would produce 1,000–1,200 carats of high-quality gemstones, with the larger ones weighing 50 to 75 carats each. Choosing this option would mean at least two, possibly three horizontal cuts through potch layers. Individual stones could be cut from each of the slabs, two of them with strong color bars. The lower color bars would produce good commercial-quality gemstones; the better ones would be exceptional.

Cutting a Museum-Quality Specimen. While cutting a single large stone would probably result in a lower total value than cutting many smaller gemstones, there are only a handful of extremely large gem opals in the world. After evaluating the rough, I thought it would be possible to get a single fine opal weighing over 1,000 ct. This was the riskiest option because of all that could go wrong in the process, but the temptation of creating something truly special while preserving the integrity of such a treasure was irresistible.

For more than 70 years, the opal had looked exactly like this. Two of the sides were still in the original condition; the other sides had been nipped or in some way opened up to expose thick color bars that appeared to penetrate the stone in a relatively even manner and on a slight angle without significant undulations. The top color bar was obviously beautiful, and part of the potential had been uncovered. But what magical display of color was still locked within?

MAKING THE FIRST CUT

I decided on the third option: creating a single large collector/museum piece. I spent hours with an intense light, mapping the stone to make an informed decision on where the cut would be.

In choosing which side would be the top of the stone, it was necessary to determine what the bottom color layer looked like. This could not be determined with certainty until the cut was made. The color bars appeared relatively level on all sides, so a saw cut through the intervening layers of potch would not sacrifice much of the valuable precious opal. I did find some small conchoidal fractures in the surface and color bars that faded out toward the edges, as seen in figure 1. There were a few very small areas of sand embedded on the top surface, but for my purposes, the entire top surface needed to be free of blemishes. My concern was that using a diamond wheel to remove them would cause me to cut through the color bar, so I decided to use polishing slurry instead. If the sand blemishes could not be removed, I would have to choose another color bar to be the top layer, and hundreds of carats would be lost.

To verify the quality of the color bars, I ground down the sides of the opal to a reasonably flat face. I also did some grinding in from the side to see the top of the color bar that appears second from the top in figure 3. My plan was to make the cut near the bottom of the potch layer below this large color bar; I would then remove the potch to bring out the beauty of the color bar. My hope was that it would have even better color than the top layer, allowing me to rotate the orientation so that the bottom would become the top of the stone.

Figure 4. The gem rough has been scribed with a black marker and is ready for the cut. Photo by Eric Gofreed/Eric Gofreed Photography.

Because of the stone's size, it was impossible to see very far into it, even with a strong light source. The rough gem material looked solid, and strong lighting did not reveal any apparent areas of sand or orange glints that would indicate internal fractures.

By this point, I had a good idea of where I wanted to make the main saw cut. I scribed the circumference of the stone with a black marker, adjusting for the slight undulations in the color bar (figure 4). It appeared I could make a good straight cut near the bottom of the potch layer under the second large color bar, leaving about a millimeter of skin on it.

All the hours of studying the stone were over; now it was time to make the cut and unlock the beauty within. When cutting opal I hold the rough, as this allows me to make very slight adjustments along the way. Holding the material allows flexibility that is not possible when the stone is held in a jig.

Figure 5. Making the first cut. Photo by Eric Gofreed/Eric Gofreed Photography.

With this stone, there were no straight or even edges or flats that I could use to safely clamp the crystal in a saw, so using a jig was not even an option.

Shortly after noon on July 4, 2014, with plenty of water in the reservoir, I turned on the saw (Gemstone Equipment Manufacturing with a 10 in. diameter diamond blade, 0.016 in. thick). As the water went flying, I advanced the opal toward the diamond blade (figure 5). In less than five minutes, the deed was done. The cut was perfect, and the beauty within was confirmed. I made three more vertical saw cuts to remove slices where nips had been taken out of the top surface. By making additional cuts with a 6 in. diamond saw blade (0.01 in. thick) rather than grinding on the wheel, I saved three additional pieces of rough that would cut smaller gem-grade opals.

The lower half of the opal had a layer of potch overlaying two additional color bars of medium intensity. This half, along with the other three pieces that were removed, has been preserved so that others can see the process that goes into the mapping, planning, and cutting of large opal rough.

FINISHING TOUCHES

Now it was time to begin the process of grinding the primary stone (figure 6) into a pleasing freeform shape that would maximize the beauty of the opal. After making the horizontal cut, there was about a millimeter of potch overlaying the color bar on the bottom of the primary stone. I ground it down almost to the color

Figure 6. Grinding the primary stone. Photo by Jim Peterson/Aspen Heights Imaging.

Figure 7. The final shaping and polishing of the stone. Photo by Theodore Grussing.

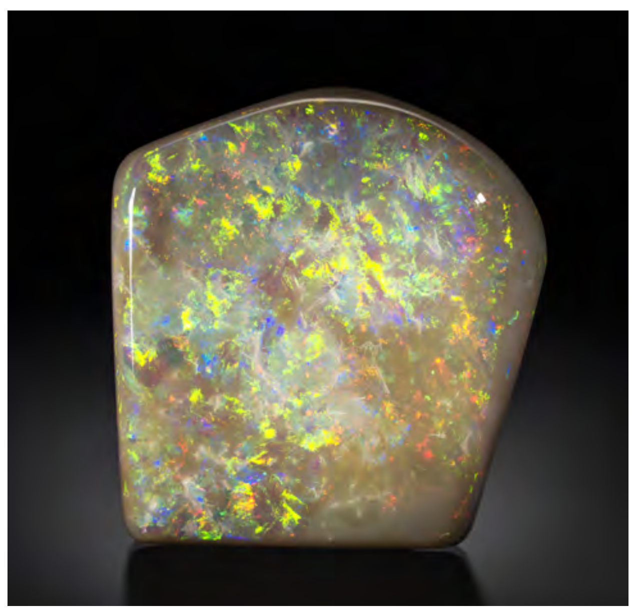
Figure 8. The planning, cutting, and shaping resulted in a handful of gem-quality opal. Photo by Theodore Grussing.

bar, which faced well with uniform play-of-color—primarily reds and blues—across the entire surface. As attractive as this lower layer was, the original top color bar still looked better, so I decided to stay with it.

My primary concern during the cutting process was to leave the top color bar essentially intact. The miner or cutter in the field removed the potch down into the color bar itself and, as shown in figure 1, the color bar was thin near the edges. This left little tolerance for removing blemishes on the surface because of the risk of going through the color bar and creating an area on the surface with no play-of-color.

I shaped the stone on my custom-made lapidary machine using 6 in. × 2.5 in. diamond wheels. Opal is rather "shocky," and too coarse of a grit can cause chipping, so I selected a 180 grit wheel for the initial shaping. From there I used a succession of 260, 600, 1200, and 14,000 grit wheels to remove the drag lines or scratches from each preceding wheel. The final shaping and polishing (figure 7) was done with a combination of cerium and tin oxides in a slurry on a flat pad. This is a very messy process, but it produces a near-perfect polish. The polishing slurry also removed the small sand blemishes on the surface. Note the two-inch aluminum tape affixed to the top of the cover over the polishing pad, which was used to catch excess slurry as it came off the wheel—crude but effective.

Figure 9. The 1,040 ct Molly Stone is currently on display at GIA's campus in Carlsbad, California. Photo by Robert Weldon/GIA.



The resulting 1,040 ct opal has play-of-color visible on virtually every side and from every angle. It is difficult to compare this stone with other large opals because there are so many variables involved. It is literally a handful of gem opal (figure 8), and there are few of its size and quality in any collection.

Every important gem deserves a name, and the author chose to name this one after his beloved dog. The Molly Stone (figure 9) is currently on loan to the Gemological Institute of America museum in Carlsbad, California, where it is on display in the Education wing.

ABOUT THE AUTHOR

Mr. Grussing started cutting gemstones and designing jewelry in 1976, when he began buying small parcels of opal and turning them into gemstones. The gem world spread into the other areas of his life, including legal representation of gem dealers in his law practice and photographing gemstones. He lives in Sedona, Arizona.

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REFERENCE

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For More on the Molly Stone

To view the opal from different angles, and to watch the cutting of the rough into a museum-quality piece, visit www.gia.edu/gems-gemology/summer-2016-challenges-cutting-large-gem-opal-rough, or scan the QR code on the right.

In Rainier's Footsteps: Journey to the Chivor Emerald Mine

Robert Weldon, Jose Guillermo Ortiz, and Terri Ottaway

Figure 1. In Colombia's Sinaí Valley, the sandstone monolith of El Pulpito hangs from a steep cliff in the top right. The Chivor mine is just out of view above the rock. Photo by Robert Weldon/GIA.

In early 2015, our team climbed a steep trail on the eastern range of the Colombian Andes, making the ascent toward the legendary Chivor emerald mine. A string of mules carried our packs, enabling us to bend to the task of the steep climb. We were retracing the steps of Peter Rainier (box A), a brilliant mine engineer with a lust for travel and adventure. Rainier took over the Chivor mine in 1926 and returned it to prominence. He later wrote a book about his experiences, titled *Green Fire*.

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As we clambered along, our gaze took in stark red coral trees blazing in full bloom, framed against a lush green landscape. We were looking for El Pulpito—"The Pulpit"—a massive rock jutting out from the mountains. Suddenly, its unmistakable silhouette came into full view ahead of us (figure 1). This classic landmark of the Chivor mine hung precariously over the Sinaí Valley as birds of prey glided by. Our visit to Colombia's most venerable emerald mine, which has produced some of the world's finest emeralds (figure 2), had begun.

PREPARATIONS FOR THE JOURNEY

In 2013, two of the authors were reflecting on Rainier's book and his adventures in search of Colombian emeralds. During the discussion we con-

Figure 2. This emerald on apatite is from the Klein pit at Chivor. Photo by Robert Weldon/GIA, courtesy of the Natural History Museum of Los Angeles County.

sulted John Sinkankas's encyclopedic *Gemology: An Annotated Bibliography* (1993). Sinkankas's assessment of *Green Fire* was decidedly mixed:

> Written in colorful, sometimes sensational terms, this work was not seriously regarded as an authentic record of modern emerald mining at Chivor, Colombia, until recently.... Nevertheless, the effort is worth it and [there are] many solid "plums" in the pudding from which solid conclusions can be drawn as to what really happened, the methods of mining employed, geological formations encountered and their significance insofar as bearing emeralds is concerned, specific knowledge of emerald occurrence, crystals found, methods of recovery, cleaning, and other data of interest and value.

Further investigation of the archives at GIA's Richard T. Liddicoat Library revealed a long-forgotten Rainier file and an album of black-and-white photographs, many of which identify him as the photographer. The images of Rainier and the mine workers, the mountainous landscapes, and the terraced mines at Chivor, as well as negatives showing impressive emerald crystals, are pieces of a provocative story that is all but lost to history. Sinkankas had purchased the album during the 1980s and added it to his personal library, which was acquired by GIA in 1989. Sinkankas also referenced Rainier's scholarly articles about Chivor in his own extensive writings about emeralds.

We decided on a new voyage to Chivor, in part to experience firsthand the challenges he might have faced. In March 2015, two of the authors, accompanied by four Colombian locality experts (please see the Acknowledgments), several pack mules, and a four-wheel-drive vehicle, embarked on a six-day expedition (figure 3).

This article spotlights the fabled Chivor mine of Colombia and its unique emeralds through Rainier's observations, archival photos, and the authors' findings. To place his story in the proper context, the article begins with an overview of the Spanish conquest of Colombian emerald territories, focusing on Chivor, and the ensuing global trade in emeralds. Finally, it leads to the rediscovery of the mine, up to the start of the Rainier era.

EMERALD CONQUESTS IN COLOMBIA

Before the time of the conquistadors, emeralds from sources such as Egypt's so-called Cleopatra's Mines and Austria's Habachtal deposit had long been established in the Old World. The discovery of New World emeralds completely upended the world's understanding of and appreciation for the gem. When Hernán Cortés entered modern-day Mexico in 1519, he received emeralds from Montezuma as gifts (Prescott, 1843). Spaniards throughout the conquered territories forcibly extracted information from the indigenous peoples regarding the emerald source, but details remained elusive for decades.

The Spanish originally assumed the source was in Peru, where emeralds were abundant among the Incas. In 1532 Francisco Pizarro captured and held for ransom the Inca emperor Atahualpa, in the region that came to be known as Peru. From the Incas Pizarro extorted gold and other items of value. An astounding treasure-filled room—containing mostly gold and silver, but also some emeralds—was assembled to free the emperor. Atahualpa was executed despite the delivered ransom, but details of the

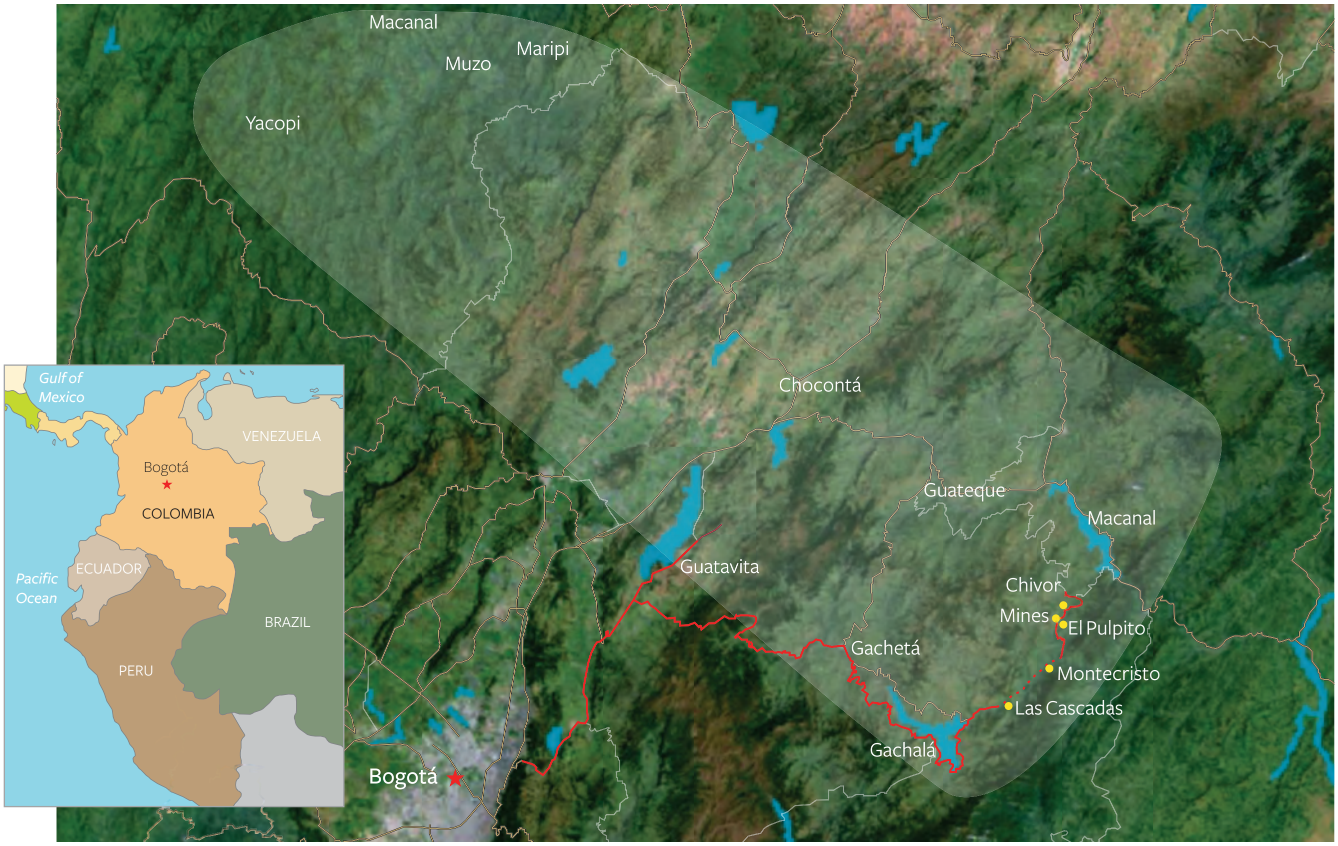


Figure 3. The Colombian Andes are the source of many historic emerald deposits. Chivor lies on the eastern side of the Eastern Cordillera, about 180 km by car from Bogotá. The authors drove from Bogotá, via Lake Guatavita, to the famed emerald deposit at Gachalá. From there they drove to Las Cascadas, the site of Peter Rainier's tea plantation and home. The rest of the journey was accomplished on foot and by mule, wandering down the Guavio Valley past Montecristo and on to Chivor. This map shows the Colombian "emerald belt," a northwest-to-southeast emerald-rich zone in the Eastern Cordillera that encompasses Muzo, Cosquez, Chivor, and Gachalá.

treasure fascinated the Spanish. In 1536 the Spanish queen issued an order to find the emerald source (Lane, 2010).

Spanish conquistador Gonzalo Jiménez de Quesada reached the Eastern Cordillera of the Andes in 1537. In this area, a territory he would later call Nueva Granada, the Spanish were actively looking for emeralds and other treasures, particularly as they began to see many more emeralds worn by the native Chibcha (figure 4). Quesada founded Bogotá in 1538 (Azanza, 1990).

Friar Pedro Simón chronicled Quesada's discovery of the first emerald source in his treatise *De Las Noticias Historiales de Las Conquistas de Tierra Firme las Indias Occidentales* (1565). He described how Quesada finally obtained the whereabouts of an emerald deposit called "Somondoco," named for the nearby village where emeralds were sorted by the Chibcha (Pogue, 1916). The Somondoco deposits would become known as "Chivor." Having located some mineralized emerald veins, Quesada sent his

Figure 4. Bogotá's Museo del Oro contains notable gold and emerald jewelry worn by the Chibcha. Photo by Robert Weldon/GIA, courtesy of Museo del Oro.

Box A: Peter W. Rainier (1890–1945)

Peter W. Rainier was a descendant of British admiral Peter Rainier (1741–1808), after whom Mt. Rainier in Washington State is named. Born in Swaziland in 1890 in the back of an ox wagon, he later attended secondary school in Natal. His parents had migrated to South Africa from Great Britain in the late 1800s, during the Transvaal gold rush (P.W. Rainier Jr., pers. comm., 2015). During his youth he traveled extensively throughout South Africa, Mozambique, Rhodesia (present-day Zimbabwe), and Nigeria. In later years, while in Colombia, he recalled growing up in Africa in books such as *My Vanished Africa* and *African Hazard*.

Following World War I, Rainier moved to Milwaukee, Wisconsin, where he married Margaret Pakel. He was hired by a New York–based consortium, the Colombia Emerald Development Corporation, to restart operations at the abandoned Chivor emerald mine. Rainier moved there in 1926, and his family joined him two years later.

Green Fire, a memoir chronicling his adventures, was published in 1942, long after his departure from Colombia. It became a literary success, and MGM eventually licensed his book for a 1954 movie of the same title but only a vaguely similar plot, starring Grace Kelly and Stewart Granger. His descriptions of the firm that hired him are veiled and generally unfavorable, though he had turned Chivor into a very profitable mine during his time as manager between 1926 and 1931. An undated Colombian newspaper clipping from GIA's Rainier archives describes production from the mine: "10,000 carats of Emeralds Reach the Capital: Yesterday, the administrator of the Chivor mine reached Bogotá, bringing with him a huge quantity of first-rate emeralds, the majority of them *gotas de aceite*." This term, Spanish for "drops of oil," is often used in the trade to designate high-quality emeralds (figure A-1; see also Ringsrud, 2008).

With Margaret, Rainier also established South America's first commercial tea plantation at Las Cascadas, set on a high slope in the Guavio Valley. His family and the plantation held Rainier's attention during downtime at the mine, or when bandits temporarily overran the concession. After Margaret succumbed to illness in 1938, Rainier abruptly lost interest in Colombia (P.W. Rainier Jr., pers. comm., 2015). He departed for Egypt, where he eventually remarried. Since Rainier's departure, the historical landmark has fallen to ruin.

Like his namesake, Peter Rainier had a distinguished military career. He fought in both world wars—in Namibia (then South-West Africa) against the Germans in World War I, and with the British Army Corps of Royal Engineers against Field Marshal Erwin Rommel's forces in World War II. One of Rainier's feats was the construction of a freshwater pipeline, which he tested with salt water. Rommel's troops overran the position to control the water supply, but upon drinking the salt water, over a thousand Germans surrendered at El Alamein ("A drink that made history," 1943; "Major Rainier's water line…," 1944).

Figure A-1. This Chivor emerald and diamond bib necklace contains 36.02 carats of emerald briolettes, 18.34 carats of step-cut Chivor emeralds, and a 5.03 ct center diamond. Photo by Robert Weldon/GIA, courtesy of Pioneer Gems.

Details of these feats were included in another one of his books, *Pipeline to Battle*. His engineering skills in North Africa earned him the nickname "The Water Bloke." Rainier achieved the rank of major with the British Eighth Army and was posthumously awarded with the Order of the British Empire, Military Division.

Following his military service, while the war was still being fought, Rainier toured North and South America, lecturing and raising funds for the British war effort. In 1945, while traveling in Canada to report on a mining property, he was severely burned in a hotel fire in Red Lake, Saskatchewan. He died from his injuries in Winnipeg on July 6, 1945. A military funeral took place in Toronto, and his remains were buried at Flagler Memorial Park in Miami.

captain, Pedro Fernandez Valenzuela, and 40 men to investigate. Simón describes the moment:

> Following much work, some [emerald crystals] of all kinds, good and not so good, were extracted. Understanding that a greater number of workers and instruments were needed to properly work the veins, [Valenzuela] returned to Turmequé to tell the general all about his findings, and to relate about the great [plains of the Orinoco River] that he had discovered from the heights of the mines, which could be seen through an aperture in the Sierras, towards the east, or where the sun rises. The general was duly impressed.

In 1537, the town of Tunja was conquered, and nearly 2,000 emeralds were seized (Sinkankas, 1981), suggesting that emeralds from Somondoco were being traded among the Chibcha. It is now known they were in fact traded with other cultures for hundreds of years—as far north as Mexico with the Aztecs, and to the south with the Incas. Chivor is singled out by historians as the source of the first emeralds traded in the Americas, and the first to be exported to the rest of the world following the Spanish conquest.

With the discovery of Muzo a year later and production beginning around 1558 (Sinkankas, 1981), Nueva Granada became the world's most important emerald source. The quantity of goods finding their way to Europe was so large that prices temporarily dropped (Ball, 1941). Colombian emeralds were initially greeted with some suspicion on the continent, perhaps because there was such a sudden influx of them, or because they were deemed too good to be true. One author (de Arphe y Villafañe, 1572) claimed that the new ones were worth only half the price of their Egyptian counterparts.

Despite these initial misgivings, the emeralds from Chivor and later Muzo were impossible to ignore. The crystals were often large, with a profoundly saturated green color—so superior to Egyptian and Austrian emeralds that those ancient deposits were destined to fall out of favor (figure 5). Emerald fever took hold of the conquistadors. In Nueva Granada, the Spanish heard of a legendary place called Guatavita, where a man coated in gold dust was ceremonially immersed into a round mountain lake. It was said that emeralds and gold objects were tossed into these waters as offerings to the Sun God, known as El Dorado. This legend only fueled the Spaniards' search for treasure.

As emeralds from Chivor began to be exported to Europe, the conquistadors took local chieftains prisoner and held them for ransom to extract the locations of other mines and the legendary El Dorado. Local populations were enslaved to mine for emeralds.

Figure 5. In the 16th century, Colombian emeralds such as these approximately 15 ct doubly terminated hexagonal crystals began to redefine quality standards for the gem. Photo by Robert Weldon/GIA, courtesy of Museo de la Esmeralda.

At Chivor, a 20 km aqueduct, built from rock with Spanish engineering and Chibcha slave labor, was used to bring water to the mine. The water was gathered in holding ponds called *tambres*, while the mining took place along the steep hillsides. After the emerald veins were exposed and the gemstones were carefully extracted, the tambres were opened, allowing the sudden rush of water to wash mining debris and overburden downhill (Johnson, 1961).

THE EMERALD TRADE

Spain was the principal importer of Colombian emeralds, though most did not stay there and surprisingly few emeralds remained in the royal treasury (Sinkankas, 1981). It is generally accepted that emeralds entering Spain were dispersed throughout the continent, mostly in trade for gold, which was the most liquid of assets. In short, plunder from the New World helped build Spain's treasure fleet and ultimately the Spanish Armada, further enabling Spain's imperial ambitions (Lane, 2010). Principal buyers of the emeralds were European royalty, clergy, and aristocrats.

In Europe, Colombia's emeralds appeared in jewelry trading and manufacturing centers such as Amsterdam and London. The Cheapside Hoard in the Museum of London, containing treasures concealed during the Elizabethan era, includes as its centerpiece a 17th-century emerald watch. The large hexagonal emerald containing the watch movement is identified as from Muzo. It would have arrived in London in the early 1600s, scarcely 50 years after the discovery of that Colombian source (Forsyth, 2013).

Emeralds were also traded for other commodities in the Far East (figure 6): textiles, spices, pearls, and other gems. It is believed that emerald commerce was often clandestine, as its high value was concealed in small packages that could be easily transported (Lane, 2010).

On the other side of the Tordesillas line, which effectively divided South America between Spain and Portugal, the Portuguese did not find emeralds in Brazil. They searched for several centuries, with little to show (Weldon, 2012). But emeralds from Colombia were exported by Spain as far away as Goa, India, where the Portuguese flourished (figure 7). According to Jacques de Coutre, one of the European merchants who traded in the area in the late 1500s and early 1600s, "It is very true that all parts of the world send pearls, emeralds, rubies and jewels of great value to East India and everyone knows full well that they ended up in the hands of the Great Mughal" (Vassallo and Silva, 2004).

Figure 6. The 75.45 ct Hooker emerald possesses an exceptional bluish green color and clarity that are often associated with the finest emeralds from Chivor. Once owned by Abdul Hamid II, who reportedly used it as a belt buckle, the emerald was acquired by Tiffany & Co. in 1911. It was refashioned as a pin and is now part of the National Gem Collection at the Smithsonian Institution. Photo by Robert Weldon/GIA, courtesy of the Smithsonian Institution.

Figure 7. The Maharaja of Indore necklace (also known as the Spanish Inquisition necklace) has resided in the Smithsonian's National Museum of Natural History since 1972. The center emerald (approximately 45 ct) and the barrel-shaped emeralds from Muzo and Chivor were cut in India in the 17th century. They are accented with Indian diamonds from Golconda. Photo by Robert Weldon/GIA, courtesy of the Smithsonian Institution.

Colombian emeralds were particular favorites of the Mughal rulers during the 1600s, such as Jahangir and Shah Jahan, who amassed gem treasures of incalculable value (Dirlam and Weldon, 2013). Many of these jewels—and the largest known single collection of emeralds—ended up in Persia, in present-day

Figure 8. This Mughal emerald (front and back views) incorporates a floral motif inlaid with gold and Golconda diamond accents. An inscription is barely discernible. From Colombia the gem made its way to India and was fashioned during the Mughal era. Photo by Robert Weldon/GIA, courtesy of Dhamani.

Iran (Meen and Tushingham, 1969). Important emeralds were skillfully carved with floral motifs and inscriptions from the Koran (figure 8).

Emeralds recovered by treasure hunter Mel Fisher from the Spanish galleon *Nuestra Señora de Atocha* in 1985 offered insight into how emeralds were exported from the New World. The *Atocha*, which sank off the coast of the Florida Keys in 1622, was part of a fleet that left port from Cartagena, bound for Spain via Havana. The ship was loaded with silver and gold ingots as well as loose emeralds and emerald jewelry, items that were detailed on its manifest. The ship's course and the type of cargo it carried revealed the supply chain of emeralds destined for Europe and Asia via Spain (Kane et al., 1989). During the colonial period, this trade would last the better part of two centuries (figure 9).

Figure 9. The cross pendant and chain pictured here are part of the wreckage of the Nuestra Señora de Atocha*, which sank in 1622 en route to Spain. Courtesy of Eileen Weatherbee. From left to right: a 422 ct emerald crystal from Cosquez, courtesy of Roz and Gene Meieran; a collection of elongated crystals from an unknown mine, courtesy of Ron Ringsrud; and the 982 ct Angel of the Andes (far right), one of the largest emerald finds from the Chivor region, courtesy of Roz and Gene Meieran. Photo by Robert Weldon/GIA.*

The first recorded mine concession at Chivor went to Francisco Maldonado de Mendoza in 1592 (Lane, 2010). A year later, realizing that the Chibcha were being exterminated, Spain issued a royal decree regarding humane treatment of the miners. In 1602 King Philip III demanded that the laws be enforced, but it was already too late: The Chibcha labor force had been almost entirely decimated. Muzo, which had been worked since around 1558, promised a much richer volume of production.

After a few more decades of sporadic mining, the concessions at Chivor were finally deserted in 1672, following an order by Spain's Carlos II to close the mine (Sinkankas, 1981; Macho, 1990). Over the next two centuries, the abandoned workings were overtaken by jungle. With Chivor shuttered, the principal focus shifted toward Muzo (Ringsrud, 2009). A timeline of important events in Chivor's history is shown in figure 10.

REDISCOVERY OF CHIVOR

Colombian mining engineer Francisco Restrepo had researched legends about the lost mines of Somondoco in the late 1880s, visiting the national library to gather information from its archives. His research yielded Friar Simón's extensive account, forgotten for almost two centuries. Friars were often paid in gold or emeralds after a conquest and therefore had

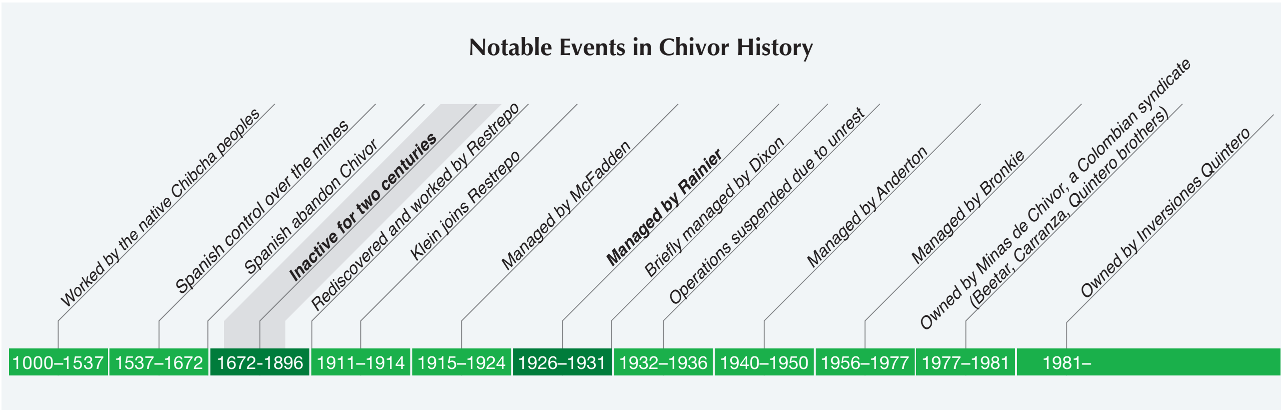


Figure 10. Rainier's time at Chivor was brief in the history of one of the longest-running gem mines in the world. Chivor's two centuries of dormancy, after the Chibcha and Spaniards abandoned the claims, stand in stark contrast with its otherwise productive life.

unique insights into these commodities. Simón's perceptions were later detailed in a series of volumes. Similar reports came from the writings of another friar, Pedro Aguado. Based on those early descriptions of the location, Restrepo spent about eight years searching the Eastern Andes before finding the lost mine in 1896 (Rainier, 1942; Johnson, 1961; G. Ortiz, pers. comm., 2015).

Restrepo did as many miners do: He diversified, controlling concessions at Chivor, which were not overseen by the Colombian government (a peculiar consequence of the 1593 royal order). By the early 1900s, Restrepo also had interests in the government-owned Muzo mine. He worked both mines for a dozen years, earning him great respect in the annals of Colombian mining. In 1911, Fritz Klein came from Idar-Oberstein to join him. Klein's connections with the Colombian president allowed him to travel freely through many of the emerald mining regions, a privilege few foreigners could claim. The tales of his adventures and emerald mining at Chivor with Restrepo are related in his 1925 book, *Smaragde Unter dem Urwald (Emeralds Under the Jungle)*, the first extensive account of the mine (figure 11).

Figure 11. Fritz Klein wrote the first detailed account of the Chivor mine, which includes the hand-painted plate by Walter Wild on the left. The plate shows typical Chivor emerald presentations, such as the rare hollow crystals on the top right, called esmeraldas vasos *("emerald cups"), courtesy of Dieter Thomas Klein. The* esmeraldas vasos *from Chivor on the right weigh 14.19 carats total. Photo by Robert Weldon/GIA, courtesy of Museo de la Esmeralda.*

Figure 12. Left: Justo Daza, pictured here next to an extension of the Spanish aqueduct, is one of the most famous emerald miners in Chivor's history thanks to his discovery of the Patricia emerald, a 632 ct colossus that resides at the American Museum of Natural History. Courtesy of Gonzalo Jara. Right: An illustration of the Patricia emerald, from Fritz Klein's Smaragde Unter dem Urwald*, courtesy of Dieter Thomas Klein.*

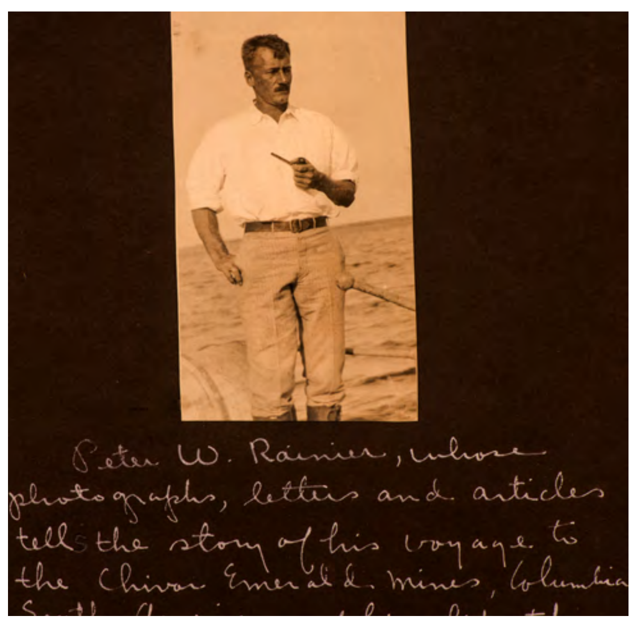
Klein left Colombia around 1914 to fight for Germany in World War I, but he later returned to oversee mining operations for Restrepo. In January 1921, a mine worker named Justo Daza (figure 12, left) uncovered what seemed to be a productive vein and pocket. Klein recalls immediately reaching into the vein "up to his elbow" and pulling out small albite, apatite, and quartz crystals. Reaching in farther, he closed his hand over a large object, which he withdrew and immediately put in his pocket without looking at it. "If what is in my pocket is an emerald, I will have fulfilled my contract," he told a colleague (Klein, 1925).

The doubly terminated hexagonal crystal that emerged from his pocket was the 632 ct Patricia emerald (figure 12, right), now housed at the American Museum of Natural History in New York City. For his part, Daza is said to have received about $10 (Keller, 1990). Chivor had intermittent mine managers after this, most notably C.K. MacFadden and W.E. Griffiths.

THE RAINIER ERA

Perched on a slope overlooking the Sinaí Valley, the emerald deposits at Chivor cling to Colombia's eastern Andes. In the deep valleys 1,220 meters below, the confluence of the Rucio and Sinaí rivers forms the Guavio River, which help frame the Chivor deposits. Shortly after his arrival in 1926, Peter W. Rainier planted an iron stake into El Pulpito at the edge of the Chivor concession. From this vantage point, he commanded a view through a gap in the Montecristo range before him. He gazed into the distance at the *llanos*, the grassy flatlands of the Orinoco River delta (figure 13).

Figure 13. Because he was usually the photographer, portraits of Peter W. Rainier are rare. Beneath this photo, he began writing an essay on his years at Chivor. Courtesy of P.W. Rainier Jr.



"Andean scenery is deceptive. So huge in its conception, that one could drop an ordinary mountain range into one of its great valleys," he later wrote in *Green Fire.* "The Chivor mine was the only point in the inner Andean ranges of the district from which the *llanos* of the Orinoco could be seen, and that distant view had provided the only clue to the rediscovery of the mine..."

The iron marker reaffirmed the locality's boundary, abandoned since Francisco Restrepo had worked the claims in the late 1800s and early 1900s. For Rainier, it was also symbolic, marking the beginning of his emerald mining odyssey (Rainier, 1942). Laying claim to Chivor is but one of the challenges many have faced in mining emeralds from this mountaintop locality. The engineers and geologists who grapple with finding "green fire" at Chivor must deal with the logistical challenges of this steep and highly inaccessible locality (figure 14), which some have described as "vertical real estate" (Johnson, 1961).

Getting themselves and their equipment to the remote location, transporting emeralds out of Chivor safely, finding suitable food, battling malaria and yellow fever (Rainier, 1942), and occasionally dealing with poisonous snakes, jaguars, and caimans in the rivers were their daily concerns. Then there were the arduous tasks of obtaining good, trustworthy labor and dealing with unpredictable roving bandits. There was no town of Chivor in those early days, so mine provisions, food, and equipment had to be brought in across the Andes by horse.

In addition to those physical challenges, Rainier had to deal with the demands of his employer, the Colombia Emerald Development Corporation. The company's executives had no idea about the difficulty of mining emeralds at Chivor. They expected him to find the mine and bring it into production immediately. But in addition to reopening the mine, clearing the debris around it, learning a new language, and hiring mine workers, Rainier had to actually locate the mineralized veins and start producing emerald. After hiring local Chibcha and toiling for weeks to build the mining infrastructure, he received a cable from his employer: "As the mine still continues to operate at a loss, the Board has regretfully decided to close it down as the funds to its credit in Bogota are exhausted. You will reserve sufficient of these funds to reimburse you for the unexpired portion of your six months' contract…" (Rainier, 1942).

Rainier decided to ignore the cable, and within a week his foreman announced the discovery of the first emerald vein. Rainier (1942) described them as "tiny hexagonal crystals, the dark green of still water and with the green a trace of blue" (figure 15).

Figure 14. Workers clear jungle and prepare terraces along the mineralized zones. Courtesy of P.W. Rainier Jr.

Rainier had a way of galvanizing the workers, inspiring them to redouble their efforts (figure 16). He

Figure 15. A miner at Chivor holds up chispas *(sparks), the name given to small hexagonal emerald crystals with a vivid color and a hint of blue. They are often indicators of larger emeralds in a vein. Photo by Robert Weldon/GIA.*

Figure 16. Left: During Rainier's time, workers pried open mineralized veins using long iron bars, and the work was done along terraces in an open-pit setting. For environmental reasons, most mining now takes place in underground tunnels, using jack-hammers. Photo courtesy of P.W. Rainier Jr. Right: Rodrigo Rojas, a miner at Corte de los Gavilanes in Chivor, takes a break from the difficult underground work in the carbonaceous black shale. Photo by Robert Weldon/GIA.

told the crew that they had only "caught the tail of the tiger" and that an even greater reward awaited the person who found the first marketable emerald. After Rainier cabled back the success of his finds, the company announced a six-month extension of his contract, giving him time to actually bring Chivor into production. About two months later, a veteran miner named Epaminondas, who had worked for Francisco Restrepo two decades earlier, uncovered a much richer vein. Such a find required discretion, as a highly valuable vein could be emptied out overnight.

Epaminondas "lifted one prehensile foot, sole upward for me to see," Rainier wrote in *Green Fire*. "Between the first and second toes was a glimpse of green. I held up my open palm and an emerald fell into it. If I live to be a hundred I shall never forget that stone."

Very soon the Chivor mine was fully terraced along its steep sides, and the emerald veins were systematically exposed (box B).

In 1929, Rainier published an article for mining engineers titled "The Chivor-Somondoco emerald mines of Colombia," in which he disclosed Chivor's production (in carats) during his time there. In it Rainier highlighted an upward trend in quantity and quality (color 1 being the best, color 5 a pale green), which he believed spelled a bright future for the mine:

YEAR	Color 1	Color 2	Color 3	Color 4	Color 5	Total
1926	0	3,170	400	11,500	28,400	43,470
1927	0	4,592	11,936	15,554	5,443	37,525
1928	0	505	10,668	4,299	7,240	22,712
1929	200	4,985	10,135	0	120	15,440

Emeralds from Chivor began showing up in world markets. News of Rainier's successes traveled quickly, inevitably making its way into Colombia's underworld. "[T]he revolver in full view of my hip tended to discourage anyone from being too inquisitive about the contents of my saddle wallets," Rainier wrote in *Green Fire*. "This was a method of carrying valuables that I followed throughout my four years at Chivor, four years in which I was to carry enough valuable emeralds into Bogotá to seriously disturb the equilibrium of the world's emerald market." *Green Fire* devotes an entire chapter to "Joaquin the Bandit," who first tried to dispute the legality of the company's claim at Chivor. Once the legal matter subsided, the battle for control of the mine turned violent.

In 1931, at the height of production—with a total of 46,250 carats produced (Sinkankas, 1981)—Rainier

Figure 17. These miners defended Chivor from armed bandits. Chris Dixon stands fourth from the left, with his two sons on either side. Peter Rainier is on the far right. Courtesy of GIA.

lost control of the mine. Not because of the bandits, though they returned later, but because his employers unexpectedly closed the mine, just as promising new emerald veins were being uncovered. With the American stock market crash of 1929, many investors' funds were drying up, as was consumer interest in buying the gems.

Having to vacate the mine at such an auspicious time was a sad moment for Rainier. As he feared, Joaquin and his bandits moved in on Chivor. Rainier, with veteran emerald miner Chris Dixon and his two sons, ultimately drove out the bandits during a nighttime raid, using guns and dynamite, even though the mine was no longer under his control (figure 17). In fact, Rainier began working the Muzo deposit under separate contract in 1933 (Sinkankas, 1981). In a wry touch, Rainier dedicated *Green Fire* in part to "Joaquin the bandit, who challenged me to a duel and was the most evil man I ever met." Rainier responded by proposing that the duel take place in a crowded marketplace using bricks at five paces. The bandit, outwitted, dropped the challenge. Again and again, Rainier skillfully outmaneuvered Joaquin, who constantly sought to ambush and kill his sworn enemy.

Rainier describes one tense standoff: "For a long time Joaquin and I stood breast to breast, while his Adam's apple oscillated violently. Then he moved back slightly. I followed at once. If he should ever attain a distance from me I was sunk. Once his revolver was out of the reach of my hand he would have me at his mercy."

According to his son, Peter W. Rainier Jr., "After my father retook Chivor from the bandits, he went back to help run the mine while my mother looked after Las Cascadas. They would communicate each night by 18-inch flashlights, as the Chivor peak was across the valley, 15 kilometers down the Guavio River. That way he could reassure her he was okay."

His wife Margaret's death precipitated Rainier's departure from Colombia in 1938. Chris Dixon and a succession of others managed Chivor after Rainier. Russ Anderton, who had previously worked in Ceylon and India as a gem buyer, was on-site briefly in the early 1940s. He wrote a book about his own adventures in Ceylon and Chivor, titled *Tic Polonga* (1953). Chivor in the 1940s and 1950s had not changed appreciably since the Rainier era. Manuel Marcial de Gomar, a Florida-based jeweler specializing in Colombian emeralds who worked at Chivor as an interpreter for Anderton, noted that horses were still required. So were weapons. Marcial de Gomar recalled that there were government-issued revolvers for those working the district.

"When you stopped at an inn after a day of travel,

Box B: The Hunt for Emeralds

Lightning seldom strikes in the same place twice, let alone hundreds of times. The odds facing an emerald miner are equally daunting. Gem minerals are notoriously difficult to find, especially those *in situ* rather than in secondary sources (figure B-1). Even when they are discovered, only a tiny fraction (0.01%) have the superlative color, size, and transparency to be used in magnificent jewelry (Sinkankas, 1981).

Emerald is arguably the most elusive of the legendary gems. Emeralds are typically found associated with pegmatites in Brazil, Zambia, Austria, South Africa, Zimbabwe, Pakistan, and Russia (Kazmi and Snee, 1989). These coarse-grained rocks are carriers of beryllium, the key component of emerald. Knowing this association gives the emerald miner an edge when determining where to explore and where to mine. In contrast, the emeralds found in Colombia occur in black shales and limestones rich in organic matter, without the benefit of pegmatites to point the way (Keller, 1981; Ringsrud, 2009).

Colombia's emerald-producing region stretches from the Muzo, Cosquez, Yacopí, and Peñas Blancas mining areas in the western zone of the Eastern Cordillera to the Chivor areas in the eastern zone. In both zones, emeralds occur within alternating beds of limestones and shales. Mineralization is limited to certain strata where it occurs in veins in the folded, fractured sediments (Oppenheim, 1948; Anderton, 1950; Sinkankas, 1981; Banks et al., 2000).

At Chivor, emeralds are found sporadically within thin albite-pyrite veins that run parallel to the bedding of the sediments. There is rarely any indication that a particular vein may produce (figure B-2). With any luck, one might encounter small pieces of the pale green opaque beryl known as *morralla*. But even the presence of *morralla* does not guarantee that gem-quality emerald will be encountered farther inside the vein. If it is, "a single emerald vein can yield anywhere from a few grams up to 6,000 grams of fine emerald crystals—a king's ransom" (Rainier, 1929, 1942).

The productive strata, which lie in the Cretaceous Guavio formation, are at least 1,000 meters thick (Johnson, 1961; Sinkankas, 1981; Keller, 1981). Peter Rainier was an experienced mining engineer with a skill for reading the rocks. He noted that within the productive strata there are three horizontal "iron bands" about 50 meters apart and up to 1 meter thick that delineate the emerald zones (figure B-3). The bands are comprised of weathered iron oxides (limonite-goethite) along with pyrite. Emeralds occur predominantly in the beds below the second and third lower bands. During Rainer's time, 75% of the emeralds mined came from below the bottom iron band, which is 30 to 182 meters thick (Rainier, 1929; Johnson, 1961). Guided by these observations and noting the subtle changes in texture between the productive strata before it bottomed out to barren strata, Rainier was able to make Chivor a profitable producer of fine emeralds once again (Rainier, 1942).

Using production figures and his knowledge of how much rock had been removed, Rainier calculated the ratio as 16 cubic meters of rock per carat of emerald (1 carat = 0.2 gram). Renders (1985) and Renders and Anderson (1987) took the next step, using Rainier's figures to calculate the amount of beryllium in solution required to precipitate the beryl/emerald yield. The numbers show that the solutions were not as rich in beryllium as once thought. An extremely low beryllium concentration of 10^{-7} (0.0000001) moles per kilogram of solution would account for the quantity of emerald estimated to occur in a vein space of 5,000 cubic meters. Analysis of the organic-rich black

Figure B-1. Emeralds in matrix, measuring 11.88 × 10.06 cm, from the Chivor mining district. Photo by Robert Weldon/GIA, courtesy of Museo de la Esmeralda.

Figure B-2. An emerald vein is pried open by hand so as not to break the valuable crystals. Photo courtesy of Gonzalo Jara.

Figure B-3. This photo of the main workings at Chivor was taken by Peter Rainier in 1930. It shows the mountainside laid bare and terraced, with groups of miners using long steel rods to remove dirt, hoping to find elusive emerald veins. Once the gems were removed, a tambre *was released to wash debris downhill, a technique employed by the Spanish using Chibcha aqueducts. Rainier described the location of the emerald zone, which is denoted by the red "X." Courtesy of P.W. Rainier Jr.*

shales showed 3 ppm on average, more than enough to produce the observed quantities of beryl (Beus, 1979).

There is a strong regional and local association between emerald deposits and evaporites (Oppenheim, 1948; McLaughlin, 1972; Banks et al., 2000). Evaporites produced by the evaporation of seawater form large beds and salt domes of gypsum (hydrous calcium sulfate) and halite (sodium chloride). Their significance becomes apparent when one examines the fluid inclusions in emerald. Halite crystals (figure B-4) are a common component pointing to the high salinity of the emerald-forming solutions (Roedder, 1963; Kozlowski et al., 1988; Ottaway, 1991; Giuliani et al., 1995).

We now know that emeralds in the Colombian deposits, from Chivor to Muzo, formed from hot evaporitic brines at 330°C. In key areas, these brines reacted with organic matter in the shales. The subsequent thermochemical process of sulfate reduction oxidized the organic matter to carbon dioxide, releasing organically bound beryllium, chromium, and vanadium (Ottaway, 1991; Ottaway et al., 1994; Giuliani et al., 1995). The resulting pressurized solutions were forced into fractured shales and limestones, where they precipitated albite and emerald. Hydrogen sulfide generated during the sulfate reduction process combined with the available iron to precipitate the large amounts of pyrite, including the now-weathered iron bands, found in the emerald-producing areas. This latter step was critical, because removal of iron from the hydrothermal system meant that it could not be incorporated into the emerald. This allowed the chromophores chromium and vanadium to impart the beautiful blue-green color and provide an underlying red fluorescence (unquenched by the presence of iron) that makes the material's color so luminous (Nassau, 1983).

The remarkable consistency in the geology of Colombian emerald deposits and in the fluid inclusion composition suggests that the hydrothermal systems at work operated under favorable structural settings (fault zones) and associations of evaporites and organic matter (Beus, 1979; Ottaway, 1991; Ottaway et al., 1994; Branquet et al., 1999). While the possibility of more Chivors and Muzos waiting to be discovered is tantalizing, they are relatively tiny targets in the steep, often inaccessible terrain.

Figure B-4. Three-phase fluid inclusions of halite, water, and carbon dioxide are typical of Colombian emeralds. Photomicrograph by Nathan Renfro; field of view 0.91 mm.

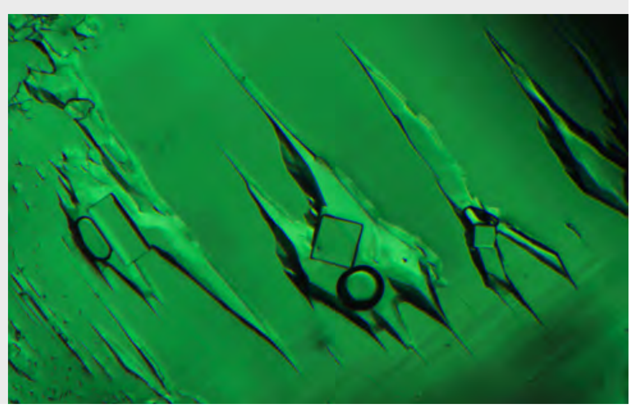


Figure 18. Willis F. Bronkie on his way to Chivor, circa 1950. Photo courtesy of Gonzalo Jara.

it was important not to get the room above the bar," Marcial de Gomar said. "If there was any revelry in the bar, those who shot in the air were liable to kill the guest above."

Another notable resident at the mine was Willis F. Bronkie (figure 18), who became the appointed trustee of Chivor Emerald Mines in 1956 and ran the company until the early 1970s. Peter Keller, a noted expert on Colombian emeralds, asserted that Rainier and Bronkie were Chivor's two "famous superintendents" and credited Bronkie with saving the Chivor mines from bankruptcy in the 1950s (Keller, 1981).

While two main mining sections remain, named Chivor 1 and Chivor 2 by Restrepo, a multitude of smaller claims have sprung up along either side of the Sinaí Valley. There is no accurate count of these independent claims today. Current production figures remain unknown, as distrust among the claimholders pervades. Independent observers suggest that because there are so many other mines throughout Colombia, Chivor only accounts for about 10% of the country's total output (Morgan, 2007). According to emerald dealer Gonzalo Jara, "Chivor has been producing, over the past ten years, a flow of emeralds which fluctuates between dry, very small quantities to occasional high yield times. In this sense, one could state that Chivor is a constant producer, year by year, but how much? Nobody knows."

At the main emerald market, Bogotá's Calle Jimenez, and at the offices and cafés around the emerald district, industry veterans examine crystals that materialize from dealers' pockets and declare their brightness and bluish traces to be "typical" of Chivor's emeralds, though there is no actual proof. Emeralds from Chivor continue to enter the market, but with the 2013 death of Muzo emerald czar Victor Carranza (at one time a part owner of Chivor) and mine owner Victor Quintero's death in 2015 and the ensuing disposition of the mines, production has remained consistently low.

THE ROAD TO CHIVOR

Getting to Chivor nearly a century after Rainier (figure 19), we experienced far easier travel conditions—and no bandits. From Bogotá we drove about 120 km east past Gachetá to Gachalá. Both regions have emerald concessions, though this was not known in the 1920s. Our group then began ascending the Andes past La Vega de San Juan, site of arguably the finest emeralds ever found in Colombia. One such gem was the 1967 find of the Gachalá emerald, a superb 858 ct gem crystal eventually donated to the Smithsonian Institution by jeweler Harry Winston. Rainier would have traveled this route or a similar one, passing through the communities of Guateque and Chocontá by a grueling combination of train, truck, and horseback (figure 20).

We descended increasingly rocky terrain toward the settlement of Palomas at the entrance to the Guavio Valley, past emerald workings. Our immediate destination was Las Cascadas, Rainier's estate and tea plantation (figure 21). The team walked the high mountain paths of the great Guavio Valley. Climbing from the main road toward the compound took 45 minutes but offered spectacular views of our ultimate destination: the mines at Chivor, approximately 15 km away. It is easy to see why the valley would have enthralled Rainier, a natural wanderer and explorer. Mountain rifts in the valley contain magnificent trees with flowering bromeliads, and waterfalls often cascade for hundreds of meters:

> Their music was in our ears that first night I spent with my family in the rough camp in the forest, and it remained as an accompaniment to our every action during the years we lived there. *Pianissimo* when the falls were mere feathery wisps in the dry season, a roaring crescendo when the rains of the wet season lashed the peaks above and the mountain torrents leaped from the terraces in solid columns of water (Rainier, 1942).

The compound was imposing nearly a century ago, the only place with electricity for hundreds of kilometers. Taking advantage of the abundant hydroelectric

Figure 19. A panoramic view of the principal mining claims at Chivor in 2015. Photo by Robert Weldon/GIA.

power for daily needs and the farm, Rainier installed a water turbine. Las Cascadas, the first tea plantation in South America, was administered by Mrs. Rainier.

Rainier describes journeying from Las Cascadas to Chivor, dawn to dark, negotiating steep Andean ascents, raging rivers, and slippery rock paths on his fast horse, Moro. It took us twice that time walking in the *dry* season, accompanied by a trio of slow-footed but willing pack mules.

The vertiginous paths down the Guavio Valley led us under a thundering waterfall and toward Montecristo, a hamlet at the border of Cundinamarca and Boyacá provinces. At nightfall we reached Montecristo and familiarized ourselves with the two-dollar-a-night accommodations. Members of the team agreed this was probably overpriced. The structure was composed of wooden planks held together by hope and covered by deeply rusted sheets of tin roofing. Unbe-

Figure 20. Left: Transportation through the Chivor region was by horse or mule. Photo by Peter W. Rainier, courtesy of GIA. Right: The authors follow Rainier's path from Las Cascadas to Chivor on foot and by mule. Photo by Robert Weldon/GIA.

Figure 21. Left: The only known photo of Las Cascadas, Rainier's home and tea plantation, was taken in the 1950s, not long after Rainier's departure. Courtesy of Dustano Martinez. Right: In 2015, Las Cascadas was a crumbling shadow of its former self; the large tree at the center of both shots forms a reference point. Photo by Robert Weldon/GIA.

knownst to Rainier, who had walked or ridden past Montecristo for a decade, fine emeralds were to be uncovered in the ravines and faults in the range above the town. Small independent mines have since been started there (I. Daoud, pers. comm., 2015).

A fresh pack of mules assisted the team as we made our way along a steep trail, finally reaching a hanging bridge over the Rucio (figure 22), barely a stream in the dry season. Chivor was within reach.

CONCLUSION

In researching this story, it became clear that much of the region's history is forgotten. Most of the history would have been lost entirely had it not been for *Green Fire* and the photographs taken by Rainier, which helped mark a productive and colorful era in Colombian emerald mining.

Rainier's struggles to find the elusive emeralds, and bring them successfully to market, is a timeless mining saga. He did this while battling natural and manmade challenges, ultimately achieving an epic triumph over adversity.

Chivor's once bountiful emeralds may have taken a back seat in terms of today's production, but the mine has a tendency to surprise with its sudden, spectacular revivals. Chivor emeralds' unique bright color,

Figure 22. This hanging bridge over the Rucio, built by Rainier, marks the crossing from Cundinamarca Province into Boyacá, very close to Chivor. Photo by Peter W. Rainier, courtesy of GIA.

Figure 23. During his brief time at the Chivor emerald mine, Peter Rainier restored the fortunes of this legendary source. His memoir, Green Fire*, illustrated the challenges of mining there and the timeless allure of its green gems. This platinum, emerald, and diamond necklace contains 23 emeralds from Chivor totaling approximately 45 carats. A combination of step-cut and round brilliant diamonds, weighing approximately 22 carats total, complements the design. Photo by Robert Weldon/GIA; necklace courtesy of Ronny Levy, Period Jewels, Inc.*

tinged with blue, and their relative lack of inclusions are attributes that fascinate global aficionados (figure 23). These emeralds captivated Rainier's attention in the 1920s and 1930s, and in turn he helped change the modern world's appreciation for the source.

Before leaving Chivor for the journey back to Bogotá, we took a day hike from the base of the Sinaí Valley along a very steep incline to El Pulpito. Undoubtedly that natural landmark will remain to guide future explorers, should the Andean jungle once again overtake the mine. On this day, we were trying to find the iron bar sunk into the rock by Rainier. It had disappeared, but the hole where it had been plunged was eventually found under a layer of dirt and grass. It was a moving discovery, an echo of Rainier's accomplishments nearly a century earlier. From the high point at El Pulpito, seeing emerald country spread before us, we enjoyed a moment of quiet contemplation. Peter W. Rainier is long gone. But at El Pulpito, his presence was felt.

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Mr. Weldon is manager of photography and visual communications and is based at GIA's library in Carlsbad, California. Mr. Ortiz is a mechanical engineer and emerald dealer who owns Colombian Emeralds Co., based in Bogotá and Los Angeles. Ms. Ottaway is a geologist and curator of the GIA Museum in Carlsbad.

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Our investigation, with help from genealogist Gena Philibert-Ortega, led us to Rainier's son. Peter W. Rainier Jr., also an author, was living in Canada and working on his latest book at the age of 89. Through his sharp memory and comments, we were able to attach names to long-forgotten faces in unmarked photos and piece together details about his father that had been left untold. We profoundly thank him.

Emerald dealers and mine owners Don Victor Quintero, Ismael Daoud, Favio Navoa, Enrique Figueroa, Misael Diáz, Alberto Sepulveda-Sepulveda, and Osbal Yovany Martinez were crucial to our visit. Although they did not know Rainier, these gentlemen provided information and stories about Chivor and Muzo and allowed us to photograph their emeralds. Gonzalo Jara supplied additional historical images and background. In California, Bill Larson opened his library to us and provided emerald specimens for photography. The Smithsonian Institution in Washington D.C. and the Natural History Museum of Los Angeles County allowed us to photograph and use images of some of their prized emerald objects.

Victor Castañeda, an emerald dealer from Gachalá who had been to several of the Rainier locations in the Guavio Valley, confirmed the locations in Green Fire*.*

Experts from Bogotá, Gachetá, Gachalá, and Chivor—Victor Castañeda, Pedro Alvio Angel Urrego, Alfonso Cuervo, and Fernando Niño Murcia, respectively—ensured safe passage through emerald country. We also relied on the kind help of experts, locals, and total strangers as we walked and rode our mules across the Guavio Valley.

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For More on Peter Rainier and Chivor

Watch video and view slide shows of the Rainier-era Chivor mine at www.gia.edu/gems-gemology/summer-2016-rainier-footsteps-journey-chivor-emerald-mine, or by scanning the QR code on the right. You'll discover the allure of Colombian emeralds from this fabled source.

G&G Lab Notes

Editors
Thomas M. Moses | Shane F. McClure

DIAMOND

Examination of the Largest Canadian Diamond

With the first major discoveries made 25 years ago, diamond mining in Canada is relatively new. The Diavik mine, located in the Northwest Territories about 300 km (190 miles) northeast of Yellowknife, began production in 2003. Today Diavik is Canada's largest diamond mine by volume, producing approximately six to seven million carats of gem-quality diamonds annually (see the lead article of this issue, pp. 104–131). Much has been reported about Diavik's extensive efforts to ensure the long-term protection of the land, water, and wildlife that are integral to local traditions and daily life in the Northwest Territories.

Adding to the significance of the Diavik mine was the spring 2015 recovery of the largest rough diamond ever found in Canada. GIA's laboratory in New York recently had the opportunity to study this historic stone. The rough weighed 187.66 ct and measured 36.96 × 32.99 × 16.80 mm. Under standard color grading lighting conditions, it appeared pale yellow (figure 1). One side of the diamond displayed clear iridescent color banding due to light interference along the cleavage planes (figure 2, left). The stone showed irregular morphology, with a tabular shape, and was dominated by cleavage faces. Some original faces with dissolution pits were clearly visible (figure 2, center).

Figure 1. This pale yellow type Ia "cape" diamond from the Diavik mine, weighing 187.66 ct, is the largest Canadian diamond to date.

When observed under a gemological microscope, the irregular surface etching limited our ability to see clearly into all areas of the diamond. A dark mineral inclusion was noted near one side of the rough (figure 2, right), but little else was readily apparent. Crossed polarizing plates did not reveal any areas of strain. The stone exhibited moderate blue fluorescence to long-wave UV radiation and faint yellow fluorescence to short-wave UV; no phosphorescence was observed. Absorption spectroscopy in the infrared region revealed that it was a type Ia diamond with a very high concentration of nitrogen. A weak hydrogen-related absorption at 3107 cm^{-1} was also recorded. UV-visible absorption spectroscopy, performed at liquid nitrogen temperature, showed typical "cape" lines, with clear absorption peaks at

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

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Figure 2. Iridescent color can be seen along the cleavage plane on one side of the stone (left). Dissolution pits are observed on the surface of the yellow rough (center), and a dark mineral inclusion is clearly visible near the surface (right). Field of view 14.52 mm (left), 4.79 mm (center), and 7.19 mm (right).

415 and 478 nm. No other absorption was detected in the UV-Vis region. These gemological and spectroscopic observations confirmed that this was a natural, untreated diamond.

The diamond, named the Diavik Foxfire, will undergo further scrutiny during the cutting process, in which it will be carefully designed, shaped, faceted, and polished. It will be interesting to see if the rough yields a significant main diamond or is cut into several smaller gems.

John King, Kyaw Soe Moe, and Wuyi Wang

Natural Colorless Type IIa Diamond With Bright Red Fluorescence

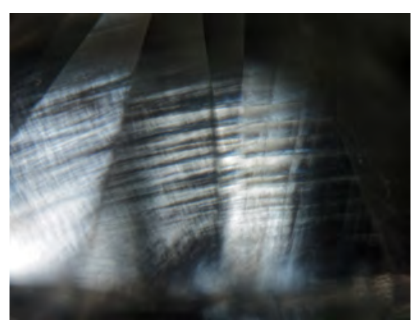
The nitrogen-vacancy (NV) center is produced in nitrogen-bearing diamond through the combination of a single nitrogen atom and a vacancy. It can exist in neutral (NV^0) and negatively charged (NV^-) states. Using photoluminescence (PL) spectroscopy, NV centers can be detected by the occurrence of zero-phonon lines (ZPL) at 575 nm for NV^0 and 637 nm for NV^-. In natural type IIa diamonds, the emissions of NV centers are usually weak, and the relative intensity of NV^0 (575 nm) is typically stronger than that of NV^- (637 nm). As a result, the vast majority of natural type IIa diamonds show blue fluorescence, attributed to the occurrence of defects such as N3 or dislocations, when excited by the short-wave UV radiation of the DiamondView. Recently, however, the Bangkok laboratory examined a natural colorless type IIa diamond that showed very bright red fluorescence due to high concentrations of NV centers.

This 0.40 ct round brilliant diamond received a D color grade and an SI_1 clarity grade based on surface-reaching fractures at the girdle and on the pavilion (figure 3). The infrared absorption spectrum confirmed a type IIa diamond with no measurable defect-related absorptions. Microscopic examination with cross-polarized light revealed a relatively strong tatami strain pattern with a weak interference color (figure 4). Further examination with the DiamondView showed that this stone exhibited an unusual red fluorescence (figure 5), similar to that of nitrogen-doped CVD synthetic diamonds. However, the DiamondView images revealed dislocation networks of typical natural type IIa diamond along with a tree-ring growth pattern, which is very rare for natural type IIa diamond but typical for natural type Ia diamond.

Figure 3. This 0.40 ct, D-color type IIa round brilliant diamond showed very bright red fluorescence due to strong emission peaks from the nitrogen-vacancy centers.

In order to detect any possibility of treatment, we employed PL spectroscopy at liquid nitrogen temperature with several laser excitations. With 514 nm laser excitation, the PL spectrum revealed very strong emission peaks from NV^0 (575 nm) and NV^- (637 nm) (figure 6). This is very rare in natural type IIa diamonds. The higher intensity of the NV^0 emission was observed. For this diamond, short-wave UV excitation

Figure 4. Viewing the diamond under cross-polarizing filters revealed a tatami strain pattern with a weak interference color, a characteristic of natural growth. Field of view 3.1 mm.



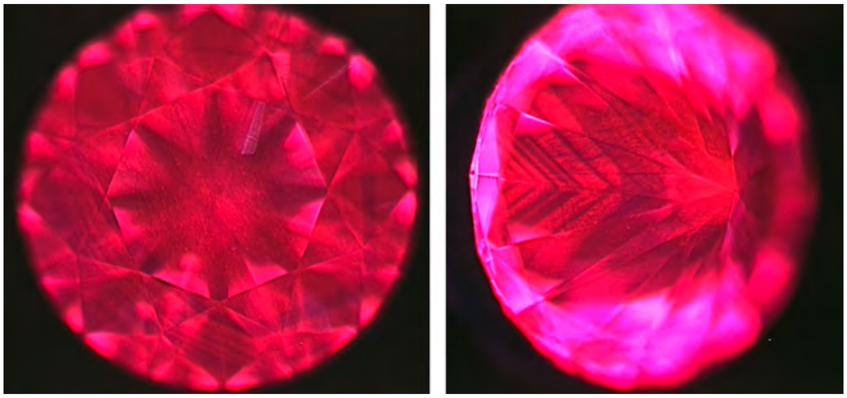


Figure 5. DiamondView images of the 0.40 ct diamond showed red fluorescence, which is unusual for natural type IIa stones. This red fluorescence was related to the intense emissions of the NV centers. Also observed was a dislocation network typical of natural type IIa diamond, along with a tree-ring growth pattern.

close to 230 nm was very effective in exciting fluorescence from the NV^-, which has a ZPL at 637.0 nm and its strong side bands at longer wavelengths. Due to the relatively high concentration of the NV^- defect, strong red fluorescence was observed.

Both spectroscopic and gemological features clearly indicated a natural diamond. The excellent color and the red fluorescence, which is rare for a natural colorless type IIa diamond, make this a notable stone.

Wasura Soonthorntantikul and Wuyi Wang

Separation of Black Diamond from NPD Synthetic Diamond

In two recent Lab Notes, we reported on a new type of synthetic diamond: nano-polycrystalline synthetic diamond, known as NPD (Spring 2014, pp. 69–71; Winter 2014, pp. 300–301). Submitted for identification in April 2016 was a 0.70 ct pear-shaped Fancy black diamond (figure 7). The diamond's infrared absorption spectrum was strikingly similar to that of the two NPD identified specimens mentioned above. It displayed very similar absorption peaks in the one-phonon region (figure 8), which can probably

Figure 6. The photoluminescence spectrum at liquid nitrogen temperature using 514 nm laser excitation displayed strong emission peaks at 575 and 637 nm due to NV^0 and NV^- centers, respectively. In natural type IIa diamonds, the intensity of NV centers is usually weaker than the diamond Raman peak at 552 nm.

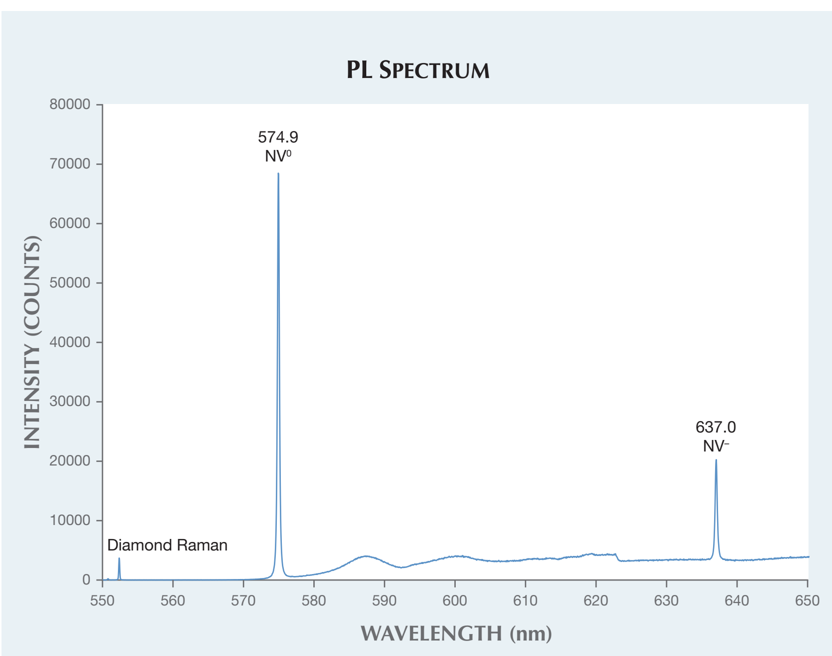
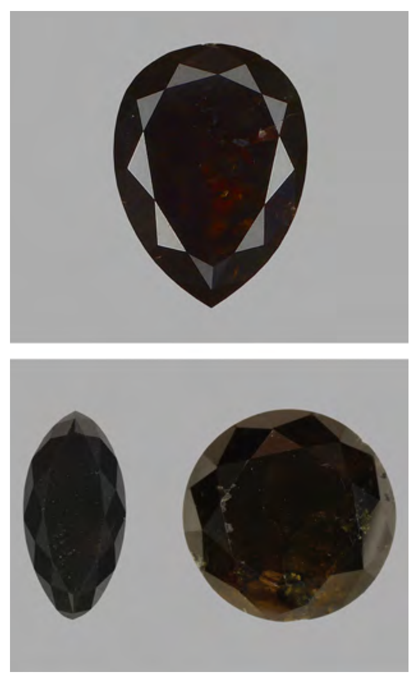


Figure 7. The 0.70 ct Fancy black pear-shaped diamond in the top photo closely resembled two NPD synthetic diamonds submitted earlier (the 1.51 ct round and 0.9 ct marquise, bottom).



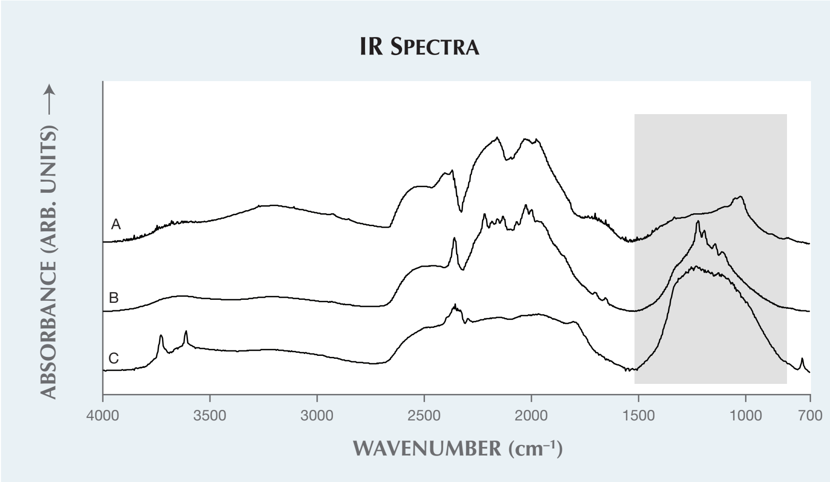


Figure 8. IR spectra of the three black samples (offset for clarity) show unusual broad peaks in the 760–1500 cm^{-1} region (highlighted in gray): 0.70 ct natural black diamond (A), 1.51 ct NPD (B), and 0.90 ct NPD (C).

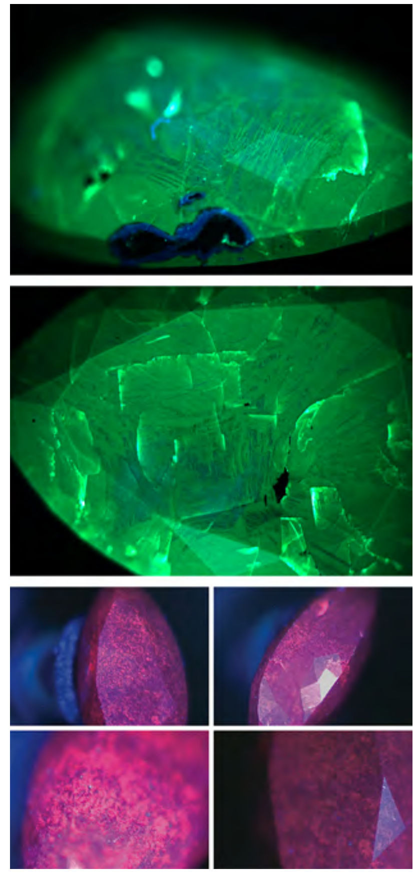


Figure 10. These DiamondView images show the fluorescence pattern and color for natural diamond (top and center) and NPD synthetic diamond (bottom).

be attributed to nitrogen.

Microscopic examination revealed an abundance of dark graphitized crystal and fracture inclusions, features often associated with black gem-quality diamonds but not unlike those observed in the NPD samples (figure 9). The challenge for gem laboratories, then, is how to separate black NPD synthetic diamonds from their natural black diamond counterparts.

DiamondView imaging offers a quick and definitive solution to this problem. NPD synthetic diamond has a distinct fluorescence pattern and structure that are obvious in the DiamondView images (figure 10). This technique can provide an instant positive identification for NPD synthetic diamond, which can be supported with further testing.

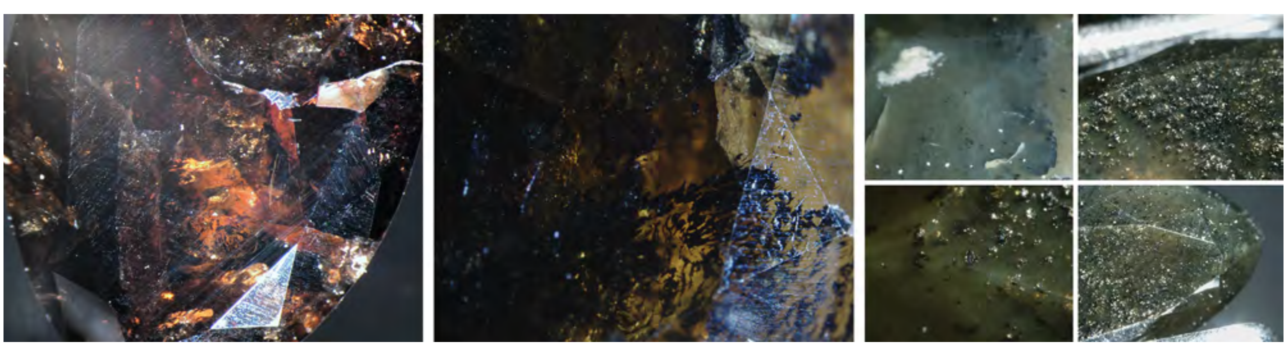
The 0.70 ct pear-shaped diamond was issued a report with a Fancy black color grade and a natural origin of color.

Paul Johnson and Kyaw Soe Moe

Unique Drilled EMERALD

A 3.39 ct emerald, as confirmed by standard gemological testing, was received by the New York lab (figure 11). At first glance it appeared to be a typical emerald with moderate clarity enhancement. It was categorized as F2, indicating that the fracturing present in the stone had a noticeable but not significant effect on the face-up appearance. Further microscopic examination of the pavilion revealed two prominent drill holes filled with

Figure 9. Natural inclusions in black diamond (left) are compared with various inclusions previously observed in NPD synthetic diamond (center and right). Field of view 6.24 mm (left) and 1.76 mm (center and right).



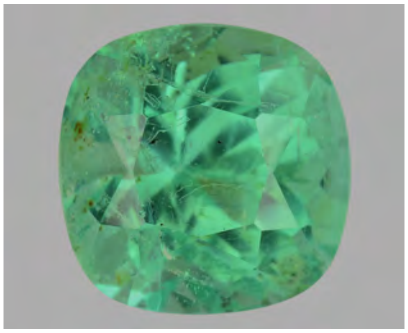


Figure 11. This 3.39 ct emerald (8.91 × 8.87 × 7.61 mm) is moderately clarity enhanced, obscuring two drill holes (not visible in this photo).

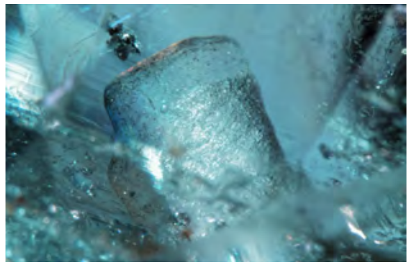


Figure 13. This drill hole shows a blue and orange flash effect along the interface between the emerald and the resin filler. Field of view 3.57 mm.

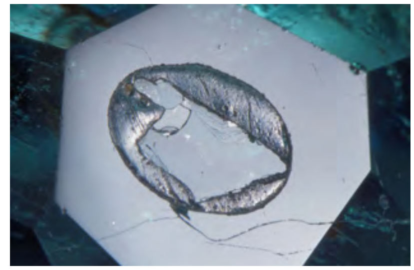


Figure 14. Examination of the drill hole in reflected light shows an emerald fragment intentionally placed in the opening, presumably to conceal the hole. Note the luster difference between the emerald and the resin filler. Field of view 3.57 mm.

a resin and emerald fragments (figure 12). The resin displayed a blue and yellow flash effect, and gas bubbles trapped in the resin were also present (figure 13). The filler had much higher relief than the emerald host and was clearly visible under reflected light due to the difference in luster between the two materials (figure 14).

The question arose as to why such a treatment would be performed on this stone. Microscopic observation did not yield any clues. One hypothesis would be that eye-visible inclusions were removed by drilling, analogous to the laser-drilling treatment well known in diamonds. Assuming this theory is true, the "enhancement" actually significantly reduced the value of this good-quality emerald. We concluded that the stone contained a resinous material in the drill holes along with emerald fragments. This was the first time GIA's New York lab had witnessed this type of enhancement in an emerald.

Edyta J. Banasiak

Figure 12. With microscopic examination, the circular outline of the drill hole is apparent on the pavilion facet of the emerald. Field of view 4.08 mm.

ORGANIC MATERIALS

Natural Blisters with Partially Filled Areas

Natural blisters and blister pearls have been the subject of previous reports in *G&G* (see Lab Notes from Fall 1992, Spring 1995, Winter 1996, and Winter 2015, and Gem News International from Fall 2001 and Winter 2009). In February 2016, four large "pearls" (figure 15) were submitted to GIA's Bangkok laboratory for identification. On first impression they appeared to differ from most pearls or blister pearls examined in the past. The specimens ranged from approximately 25.06 × 18.31 × 13.41 mm to 55.90 × 13.89 × 7.96 mm, and they weighed 32.33,

Figure 15. The four large baroque blisters examined are shown alongside a Pinctada maxima *shell (left), a* Pteria sterna *shell (second from the left) and two* Pteria penguin *shells.*

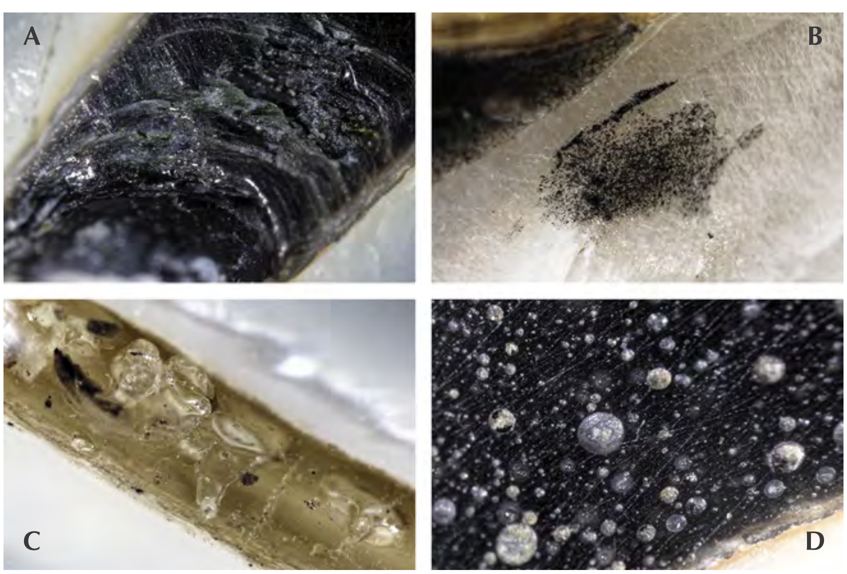
Figure 16. Dark and cream-colored bands on the bases appeared to be organic-rich formations.

37.20, 41.41, and 52.17 ct. Two of the items were white, and the other two were silver and orangy brown.

All the samples had eye-visible areas on their bases and around their outlines where they had obviously been worked or cut to either remove them from their shell hosts or improve the symmetry (in some cases both). These are telltale signs of blisters and blister pearls, since both must be removed from the shell to be presented in loose form. What caught our attention was the fact that all four items possessed dark or cream bands on their bases (figure 16). These bands appeared to be organic-rich formations, noted in some pearls and more commonly in shells, yet this did not turn out to be the case in three of the samples.

The items were considered blisters rather than blister pearls (E. Strack, *Pearls*, Ruhle-Diebener-Verlag, Stuttgart, Germany, 2006, pp. 115–127). This determination was based on external appearance and features, the "work" that had taken place on them in relation to where they were likely removed from the shells, and the results of real-time X-ray microradiography (RTX), which revealed growth arcs following the shape of the blisters to varying degrees.

Figure 17. A: Part of the dark conchiolin-rich curving band on the flat base of the 32.33 ct white blister; field of view 2.88 mm. B: Black pinpoint particles in the transparent near-colorless filler on the base of the 37.20 ct colored blister; field of view 1.20 mm. C: Distorted bubbles in the transparent filler on the base of the 41.41 ct white blister; field of view 2.40 mm. D: Obvious bubbles in the filler on the base of the 52.17 ct colored blister; field of view 2.40 mm.



The curving black band on the base of the smallest white blister contained translucent to opaque organic-looking material characteristic of conchiolin (figure 17A), one of the constituents of pearls and shells. The remaining three blisters had structures within their bands that did not match the structure observed in the first blister. The bands in the two orangy brown blisters consisted of an essentially transparent near-colorless substance in which minute black pinpoint particles imparted an overall black color (figure 17B). Meanwhile, the band in the remaining white blister showed areas of completely transparent near-colorless material and other areas of the same near-colorless material, mixed with small pieces of what appeared to be shell fragments. Distorted bubbles were clearly visible in the transparent areas on the base of the partially filled white blister (figure 17C) and one of the colored blisters (figure 17D); no obvious bubbles were seen in the other blister. RTX also revealed the extent of the filling on the bases of the three blisters.

Raman spectroscopy of the near-colorless filled areas of the two colored blisters did not show any polymer or resin peaks that matched those found in the white blister's filling. Therefore, we conducted basic testing on all three samples with a very carefully placed hot point in areas of the filling where some damage or abrasion already existed. The unmistakable plastic odor and melting of the tested areas was enough to confirm the artificial nature of the fillers. Interestingly enough, the fillers did not display a noticeable fluorescence under long-wave or short-wave ultraviolet light, but the two orangy brown blisters did exhibit distinct orange to orange-red fluorescence, which is characteristic of the porphyrins (naturally occurring pigments) known to exist in *Pteria* species shells of similar coloration (L. Kiefert et al., "Cultured pearls from the Gulf of California, Mexico," Spring 2004 *G&G*, pp. 26–38). Out of curiosity, we also checked the dark conchiolin-rich band in the smaller white blister with the hot point and fluorescence. It was no surprise to smell a distinctly unpleasant organic reaction from the band and see a weak chalky yellowish reaction under UV lighting.

These four blisters were good examples of this material, and three of them were the first partially filled blisters to be examined by GIA's Bangkok laboratory. The three partially filled blisters show that even material with relatively low market value may be treated in some way, and buyers should always be aware of what is being offered to them.

Areeya Manustrong

Unusual Yellowish Green SPINEL

Gem-quality spinel ($MgAl_2O_4$) occurs in a variety of colors based on the trace elements present within the stone. While synthetic spinels are available in almost any color, some colors are rarely found in natural spinel. The New York lab received a 2.54 ct light yellowish green spinel with unusually strong green fluorescence (figure 18). This variety of color, along with the strong fluorescence (in both long-wave and short-wave UV radiation) is rare in natural spinel, and we needed proof that this stone was not synthetic.

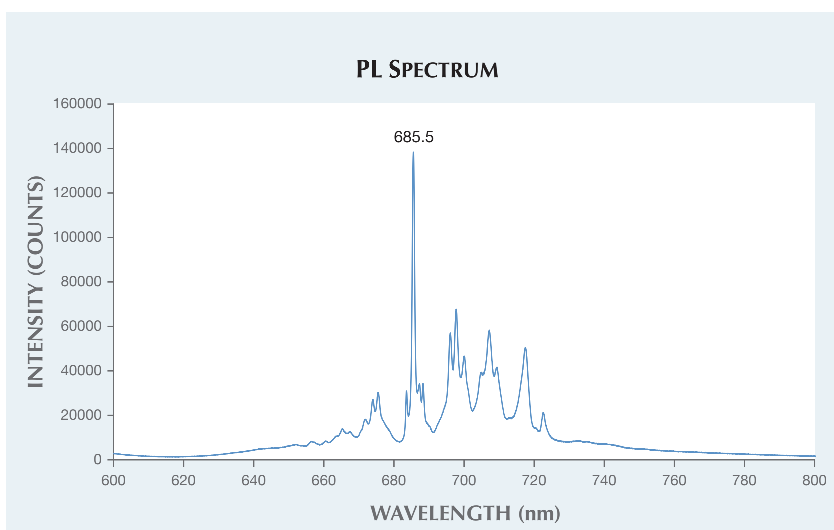
A refractive index of 1.715 suggested the stone might be natural (flame-fusion synthetic spinels typically have an RI of 1.728). Microscopic examination revealed a very small fingerprint shallow to the table facet. While not conclusively diagnostic for natural origin, it supported the possibility. When observed under cross-polarized filters, the stone revealed very little strain, more consistent with a natural spinel. To confirm natural origin, PL spectra and trace element chemistry data were collected.

Figure 18. This 2.54 ct yellowish green spinel is shown under daylight conditions (left) and short-wave UV light (right).

The PL spectra were collected at room temperature, using 514 nm laser excitation. The sharp and defined chromium emission features, with the strongest peak at approximately 685.5 nm (figure 19), verified that the stone was natural and unheated (S. Saeseaw et al., "Distinguishing heated spinels from unheated natural spinels and from synthetic spinels," 2009, http://www.gia.edu/gia-news-research-NR32209A). Heat treatment typically broadens and shifts the position of PL peaks (a similar effect is seen in synthetic spinels). Using laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS), high concentrations of natural trace elements were measured—particularly lithium, gallium, zinc, and beryllium. This reinforced our finding that the spinel was natural.

The stone also exhibited relatively high levels of manganese and iron. Fe can play various roles as a chromophore in spinel, depending on coor-

Figure 19. Well-defined chromium emission features in the photoluminescence spectrum confirm natural, unheated spinel.



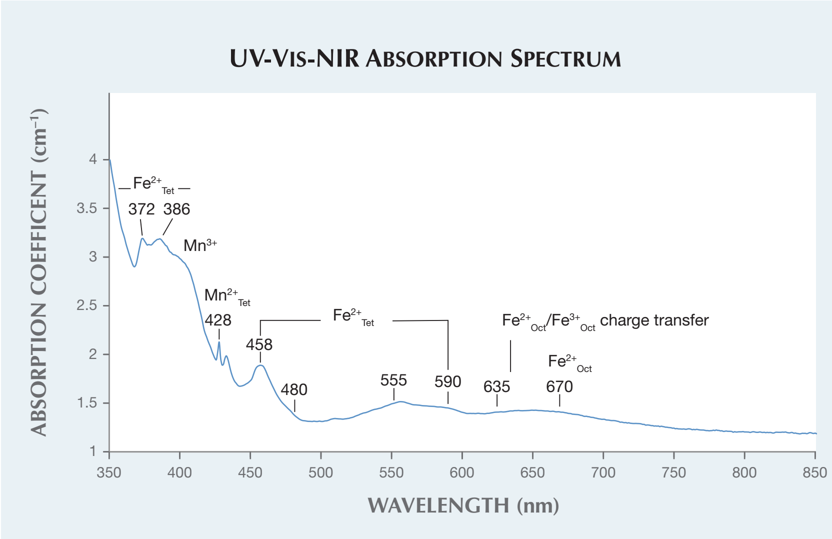


Figure 20. In the spinel's UV-Vis-NIR absorption spectrum, the combination of iron and manganese peaks produces a transmission window in the green region of the visible spectrum.

dination within the crystal structure (divalent substitution of Mg and trivalent or divalent substitution of Al), but it is mostly responsible for different shades of blue and greenish blue (V. D'Ippolito et al., "Color mechanisms in spinels: cobalt and iron interplay for the blue color," *Physics and Chemistry of Materials*, Vol. 42, 2015, pp. 431–439, http://dx.doi.org/10.1007/s00269-015-0734-0). Mn (divalent substitution of Mg and trivalent substitution of Al) is known to act as a yellow chromophore (among other colors) in spinels (F. Bosi et al., "Structural refinement and crystal chemistry of Mn-doped spinel: a case for tetrahedrally coordinated Mn^{3+} in an oxygen-based structure," *American Mineralogist*, Vol. 92, 2007, pp. 27–33, http://dx.doi.org/10.2138/am.2007.2266). The combination of Fe and Mn within the crystal structure provided a transmission window in the green region of the visible spectrum (figure 20). Using a charge-coupled device (CCD) detector and a long-wave UV light source, the green fluorescence emission band was calculated to be centered at approximately 520 nm. This luminescence was attributed to Mn^{2+} cations (Summer 1991 Lab Notes, pp. 112–113). The fluorescence could have contributed to the overall color of the stone by adding more green hue through emission.

This was one of the most unusual colors of spinel examined by GIA.

Akhil Sehgal and Daniel Girma

SYNTHETIC DIAMOND

Large Blue and Colorless HPHT Synthetic Diamonds

The technology for producing gem-quality synthetic diamonds is making rapid progress. In May 2016, GIA's Hong Kong laboratory examined five large HPHT synthetic diamonds grown by New Diamond Technology (NDT) in St. Petersburg, Russia (table 1). Examination confirmed that all of them had the known characteristics of HPHT synthesis.

Two of the synthetic diamonds were color graded as Fancy Deep blue (figure 21). The 5.26 ct heart shape and the 5.27 ct emerald cut both surpassed the previous record for largest blue HPHT synthetic, a 5.02 ct specimen reported very recently (Spring 2016 Lab Notes, pp. 74–75). Infrared absorption spectroscopy showed that both were type IIb, with strong absorption bands from boron impurity. We observed the typical color banding of HPHT synthetics, with more blue color concentrated in the {111} growth sector. PL analysis at liquid nitrogen temperature with various laser excitations revealed no impurity-related emissions, indicating these stones were surprisingly pure in composition and lacking in defects.

The other three samples were colorless (figure 22). The largest one was a 10.02 ct emerald cut with E color equivalent. This stone was previously reported in 2015 (R. Bates, "Company grows 10 carat synthetic diamond," *JCK*, May 27, www.jckonline.com/2016/01/20/company-grows-10-carat-synthetic-diamond). The round cut

Figure 21. The largest blue HPHT synthetic diamonds to date: a 5.26 ct heart shape and a 5.27 ct emerald cut. Both were graded as Fancy Deep blue.

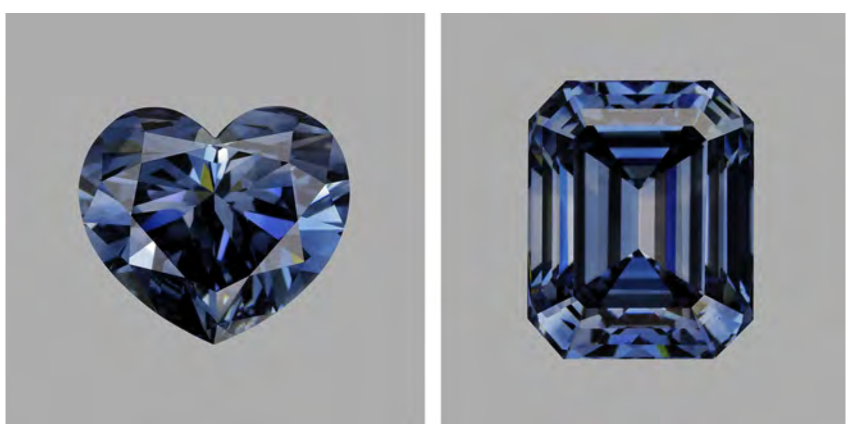


TABLE 1. Large HPHT synthetic diamonds recently examined by GIA.

Sample	Weight (ct)	Cut	Color	Clarity
1	5.26	Heart	Fancy Deep blue	VVS_2
2	5.27	Emerald	Fancy Deep blue	VS_1
3	10.02	Emerald	E	VS_1
4	5.06	Round	D	VS_2
5	5.05	Heart	D	VS_2

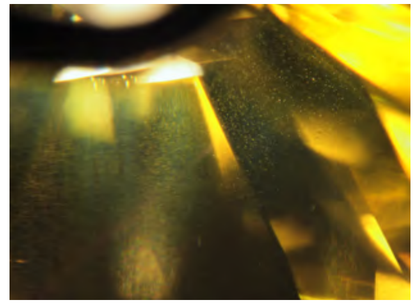


Figure 23. Under darkfield illumination, the pinpoint flux cloud is seen throughout the diamond. Field of view 3.57 mm.

weighed 5.06 ct and the heart shape 5.05 ct; both were graded as D color equivalent. Infrared absorption spectroscopy confirmed these three were type IIa diamond, but with a very weak boron-related absorption band at ~2800 cm^{-1}. PL spectroscopy revealed very weak emissions from the $[Si\text{-}V]^-$ doublet at 737 nm, the Ni_i^+ doublet at 884 nm, and NV^0 at 575 nm.

For all five samples, multiple growth sectors were observed in DiamondView fluorescence images, showing features similar to other HPHT synthetic diamonds. Strong blue phosphorescence was also detected. Unlike natural type IIa or IIb diamonds, they showed no dislocation or strain when examined under a cross-polarized microscope, a strong indication of high-quality crystallization. Their clarity ranged from VS_2 to VVS_2, attributed to a few tiny metallic inclusions trapped during diamond growth. No fractures were observed. All of these gemological and spectroscopic features are consistent with typical HPHT synthetic diamonds. This material can be accurately identified with GIA's existing protocols for analysis.

In addition to their size, these five HPHT synthetic diamonds displayed gemological features comparable to those of top-quality natural diamonds, when graded using the system for natural diamonds. This group of laboratory-grown diamonds demonstrated the quality and size HPHT growth technology has achieved. It is obvious that more and more high-quality HPHT synthetic diamonds, including those with significant size, will be introduced to the jewelry industry. GIA's decades of research into both HPHT and CVD synthetic diamonds allows for the ready identification of these synthetic diamonds.

Wuyi Wang and Terry Poon

Yellow Synthetic Diamond with Nickel-Related Green Fluorescence

Gem-quality yellow synthetic diamonds have been a part of the industry for some time now. The gemological properties used to identify these synthetics have been extensively documented (see J.E. Shigley et al., "A chart for the separation of natural and synthetic diamonds," Winter 1995 *G&G*, pp. 256–264).

GIA's New York laboratory recently tested a 0.99 ct synthetic diamond with Fancy Vivid yellow color, disclosed as a product of HPHT (high-pressure, high-temperature) growth, which showed some unusual gemological features. Its UV-Vis absorption spectra showed a smooth rise from 500 nm to higher energy. The mid-IR absorption spectra indicated a type I diamond with isolated nitrogen (C-center) responsible for the intense yellow color. The sample displayed a moderate greenish yellow fluorescence under long-wave UV and slightly stronger greenish yellow fluorescence under short-wave UV. It had a noticeable

Figure 22. The emerald cut on the left is the largest colorless HPHT synthetic diamond ever reported (10.02 ct, E color). The other two, a 5.06 ct round and a 5.05 heart, both had D color.

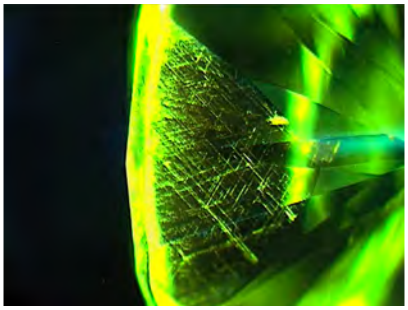


Figure 24. This DiamondView image shows the unusual green crosshatched pattern in the hourglass structure of the HPHT-grown synthetic.

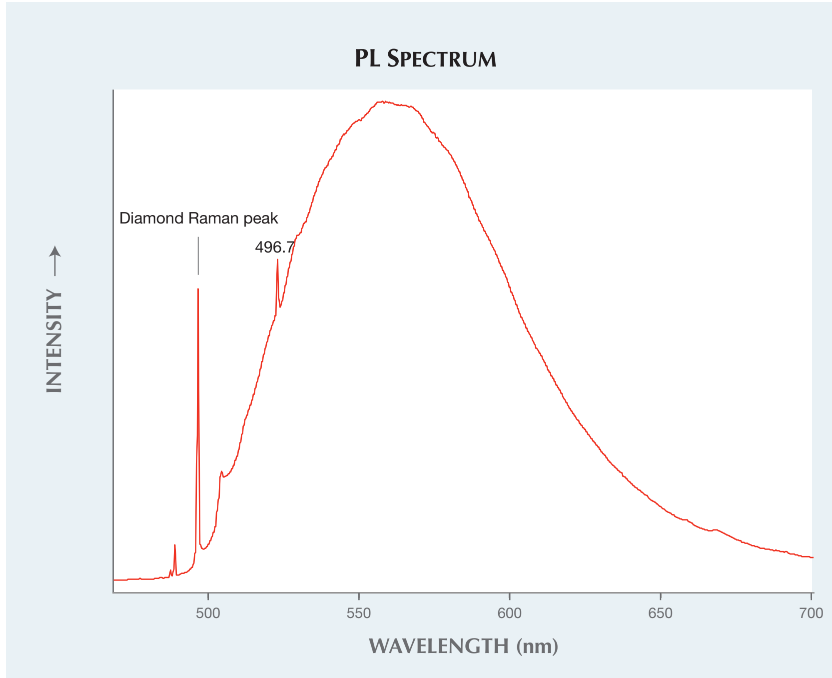


Figure 26. PL spectroscopy with blue (457 nm) laser excitation shows the S3 emission band (496.7 nm), which is responsible for the HPHT synthetic diamond's green fluorescence.

pinpoint flux cloud throughout (figure 23) and obvious yellow color zoning following the growth sectors—both characteristic gemological features of a yellow HPHT-grown synthetic diamond.

Unlike other yellow HPHT-grown synthetics, the DiamondView images showed an unusual green fluorescent crosshatched pattern within the hourglass structure (figure 24). This closely resembles the pattern seen in natural diamonds, which means the synthetic could have easily been mistaken for a natural diamond. Under cross-polarized light, it showed a mottled strain pattern with moderate birefringence colors (figure 25). Most yellow HPHT-grown synthetics do not show a clear strain pattern and have weak birefringence colors. Further examination with PL spectroscopy using blue (457 nm) laser excitation showed that the green fluorescence was caused by the S3 defect (496.7 nm, shown in figure 26), which is due to the presence of nickel—a very unusual feature for an HPHT-grown synthetic diamond.

This yellow HPHT-grown sample with gemological features we had not seen before shows once again how synthetic diamonds can be mistaken for natural diamonds. Caution must be taken, and careful gemological and spectroscopic analysis is essential.

Lisa Kennedy and Paul Johnson

Figure 25. Under cross-polarized light, the HPHT synthetic exhibited a mottled strain pattern with moderate birefringence colors. Field of view 4.79 mm.

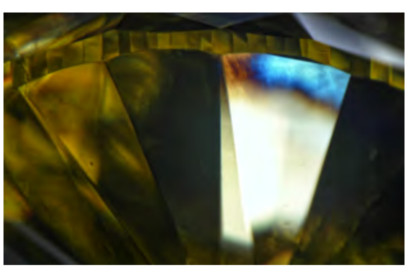


PHOTO CREDITS:
Sood Oil (Judy) Chia—1, 11, and 18 (left); Kyaw Soe Moe—2; Nuttapol Kitdee—3; Charuwan Khowpong—4; Wuyi Wang—5; Jian Xin (Jae) Liao—7 and 18 (right); Paul Johnson—9 and 10; Edyta J. Banasiak—12, 13, and 14; Lhapsin Nillapat—15 and 16; Kwanreun Lawanwong—17; Johnny Leung—21 and 22; Lisa Kennedy—23, 24, and 25.

G&G Micro-World

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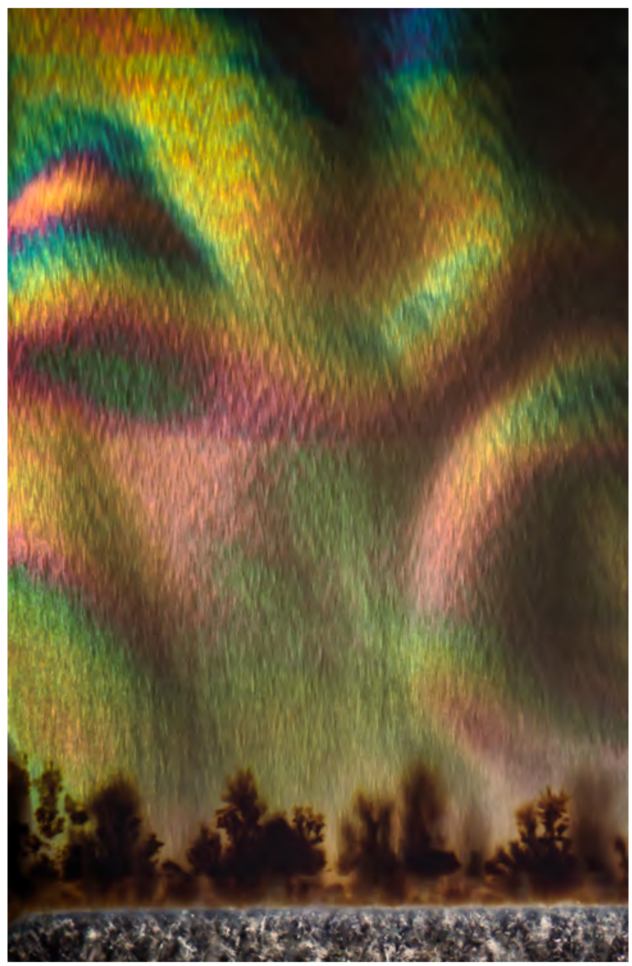
Aurora Iris Agate

When solar wind interacts with the earth's magnetosphere, spectacular multicolor light shows occur. This phenomenon is referred to as an aurora borealis in the Northern Hemisphere and an aurora australis in the Southern Hemisphere. This author recently examined an iris agate that provided a microscopic scene remarkably similar to an aurora (figure 1). The 1.67 ct carving seen in figure 2 was fashioned by Falk Burger (Hard Works, Tucson, Arizona). Burger took advantage of this quartz's unique growth texture by carving the agate's back, producing a wispy iridescent effect that is visible when using a point light source. Along the lower portion of the gem was a thin layer of crystalline quartz with a seam of pyrolusite dendrites between the crystalline quartz and microcrystalline iris agate. The combination of these layers gives the viewer the impression of an aurora occurring over a forest-rimmed frozen lake (see video at www.gia.edu/gems-gemology/aurora-iris-agate-carving).

Nathan Renfro
GIA, Carlsbad

Figure 1. In transmitted light, this skillfully carved iris agate displays a scene reminiscent of an aurora. Photomicrograph by Nathan Renfro; field of view 5.28 mm.



Inclusions in Burmese Amber

Burmese amber has been well documented in the paleontological literature, but is overshadowed in the gemological

About the banner: Columnar hexagonal graining, seen in some Colombian emeralds, creates a roiled appearance called gota de aceite *(Spanish for "drop of oil"). The optical effect is seen here using shadowed transmitted illumination. Photomicrograph by Nathan Renfro; field of view 3.23 mm.*

Editors' note: Interested contributors should contact Nathan Renfro at nrenfro@gia.edu and Jennifer-Lynn Archuleta at jennifer.archuleta@gia.edu for submission information.

GEMS & GEMOLOGY, VOL. 52, NO. 2, pp. 198–205.

Figure 2. The 1.67 ct iris agate, shown here in transmitted light (left) and reflected light (right) was carved to showcase the dynamic nature of the iridescent colors. Photos by Kevin Schumacher.

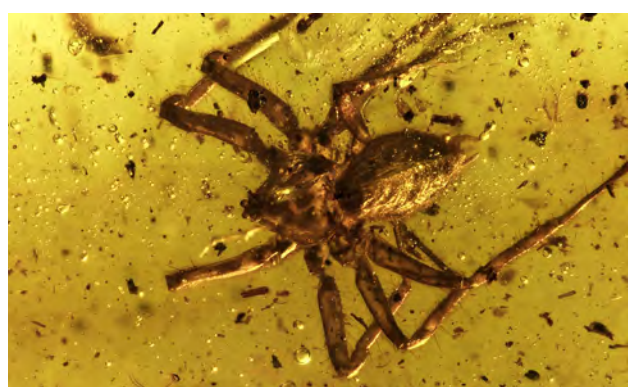
community by material from the Dominican Republic and the Baltic area. Despite the armed conflict in the Hukawng Valley, possibly the world's largest tiger reserve, accessibility has improved and amber production has steadily increased since 2014. As a result, more Burmese amber is reaching the marketplace. We have observed rising interest in the Bangkok, China, and Hong Kong markets, with specimens containing large inclusions of flora and fauna in great demand and commanding high prices. The samples presented here (figures 3–5) were acquired during a January 2016 field expedition to the Hukawng Valley and are now part of the GIA research collection.

These amber specimens are interesting because they potentially preserve evidence from biological environments of 80 to 100 million years ago (G. Shi et al., "Age constraint on Burmese amber based on U–Pb dating of zircons," *Cretaceous Research*, Vol. 37, 2012, pp. 155–163, www.sciencedirect.com/science/article/pii/S0195667112000535). They are significantly older than amber from the Dominican Republic, estimated at 25–40 million years old) and the Baltic region, which are about 25–28 million years old (D. Penney, *Biodiversity of Fossils in Amber from the Major World Deposits*, Siri Scientific Press, Manchester, United Kingdom, 2010).

Victoria Raynaud, Vincent Pardieu, and Wim Vertriest
GIA, Bangkok

Figure 3. This Tropidogyne *flower is still attached to its stem and has a small flea-like bug near its right side, as seen with darkfield and fiber-optic illumination. Photomicrograph by Victoria Raynaud; field of view 5.97 mm.*

Figure 4. This spider is surrounded by small air bubbles and plant debris. It is very easy to resolve fine details, such as individual hairs and different sets of eyes. The sample is illuminated with a combination of diffuse brightfield and fiber-optic light. Photomicrograph by Victoria Raynaud; field of view 7.20 mm.



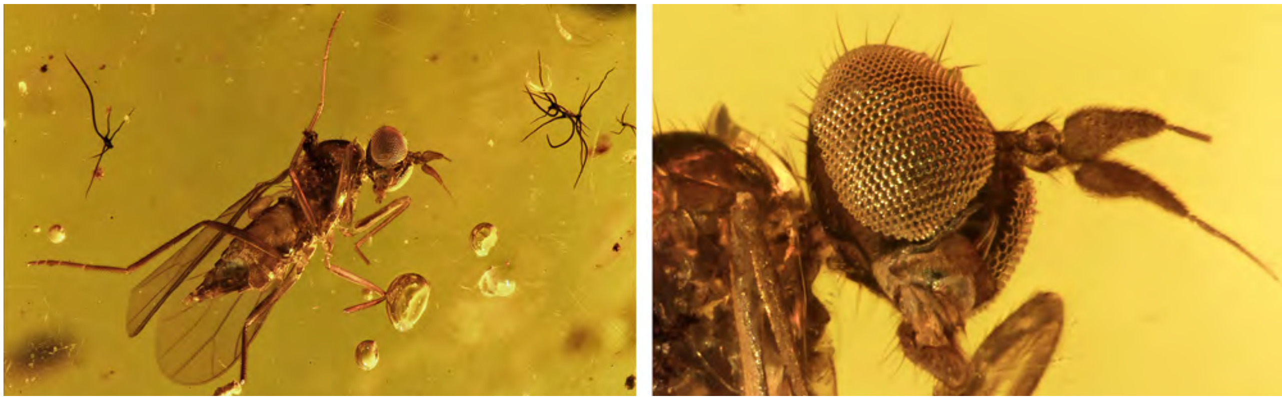


Figure 5. Left: The delicate features of this fly, particularly its wings, are surrounded by gas bubbles and trichomes (hair-like structures that grow on plants). Right: This image demonstrates the excellent preservation qualities of amber, as evidenced by the detailed structure of the fly's eye. Photomicrographs by Victoria Raynaud; field of view 4.80 mm (left) and 0.86 mm (right). Brightfield and fiber-optic illumination.

Chalcedony with Quartz Windows

A translucent white chalcedony specimen containing a few small transparent quartz crystals was fashioned into a decorative polished plate by Falk Burger (Hard Works, Tucson, Arizona). One intriguing feature of this piece is that most of the transparent quartz crystals were aligned with their c-axes parallel to each other. When they were transected perpendicular to this axis during the polishing process, angular transparent windows were created, each displaying trigonal symmetry within their otherwise translucent chalcedony host. Interestingly, even though the white chalcedony was polished into a plate, it still showed a rather curious angular-looking three-dimensional texture. When examined between crossed polars,

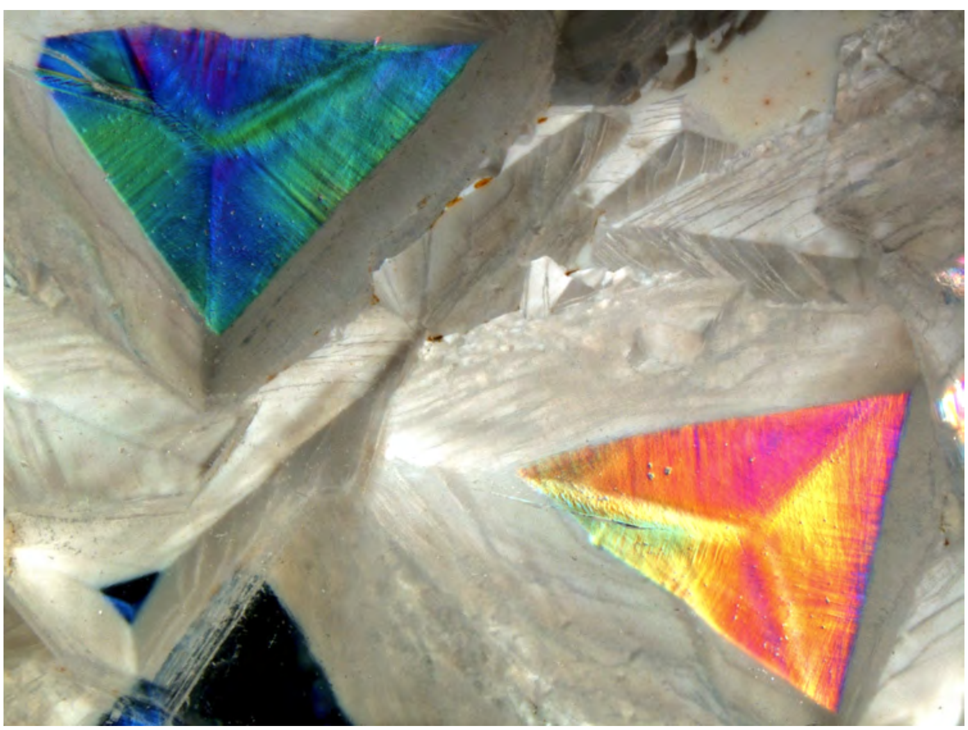


Figure 6. The trigonal windows of quartz found throughout this translucent white chalcedony displayed vibrant interference colors when examined between crossed polars. The black triangles in the lower left corner are also quartz. Photomicrograph by John I. Koivula; field of view 15.5 mm.

Figure 7. “Pond Life,” a 50.95 ct orbicular chalcedony cabochon measuring 48.5 × 27.0 × 5.5 mm, evokes a pond. The “frog eggs” are actually iron-containing inclusions surrounded by the host’s concentric growth. Photo by Elise A. Skalwold.

the triangular quartz windows ignited with vibrant interference colors (figure 6) due to Brazil-law twinning in the crystals.

John I. Koivula
GIA, Carlsbad

“Pond Life” Orbicular Chalcedony

The seemingly infinite combination of growth features and inclusions seen in microcrystalline quartz fires the imagination, often evoking visual metaphors (see “Aurora Iris Agate” in this column). Such is the case with the orbicular chalcedony seen in figure 7. From a piece of non-descript tumbling rough purchased in 2011, Paul Stalker (Stones by Stalkers, Tioga, Pennsylvania) delighted in creating what he christened “Pond Life,” as the 50.95 ct piece’s polished appearance resembles frog eggs within a pond.

Exploring the interior of such microcrystalline varieties of jaspers and agates can be just as fascinating as exploring inclusions within single-crystal quartzes, though these opportunities may be overlooked when dazzled by complex macro features. Orbicular chalcedonies such as this ocean jasper are particularly interesting. Here, iron-containing inclusions such as limonite, goethite, and hematite are surrounded by the concentric growth of the host material, which displays the unique fibrous texture found in some types of chalcedony (figure 8, left). Bundles of fibers composed of crystallites are combined with mutually complex optical orientations, giving rise to the eye-visible effect. While beautiful in transmitted, reflected, and polarized light, the addition of various contrast filters can dramatically enhance the details of these subtle growth features, making them easier to study, as well as creating stunning images of a specimen’s inner world (figure 8, right). For more on advanced filtering techniques, see Fall 2015 Micro-World, pp. 328–329.

Elise A. Skalwold
Ithaca, New York

Garnet Inclusion Illusion

A cleverly designed “garnet in quartz” double cabochon represents a new and unexpected challenge for gemologists, collectors, and designers who intend to feature inclusion gemstones in their jewelry lines. This assembled inclusion consists of a fragment of pyralspite-series garnet sandwiched between two quartz cabochons (figure 9). The garnet and quartz were identified with optical and Raman spectroscopy, respectively, at GIA’s Carlsbad laboratory. While the specimen creates the illusion of being natural, clues to its artificial origin include air bubbles and the fragment itself, which shows neither crystal faces nor the rounded appearance of an etched or eroded crystal. Rather,

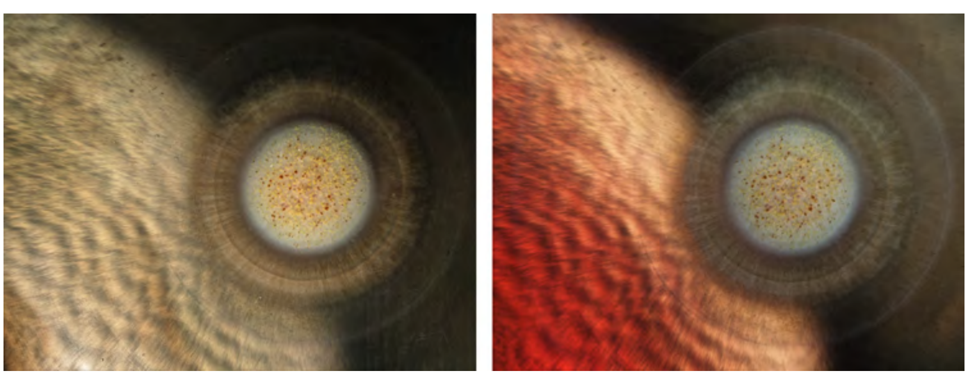


Figure 8. The use of a red contrast filter with transmitted light (left) dramatizes growth textures, making them easier to study than with unfiltered transmitted light (right) while creating an aesthetically pleasing image. Photomicrograph by John I. Koivula; field of view 4.0 mm.

Figure 9. At first glance, this 42.88 ct quartz double cabochon measuring 28 × 18.5 × 15 mm resembles a beautiful garnet-included quartz gem. Photo by Elise A. Skalwold, from the Si and Ann Frazier Collection.

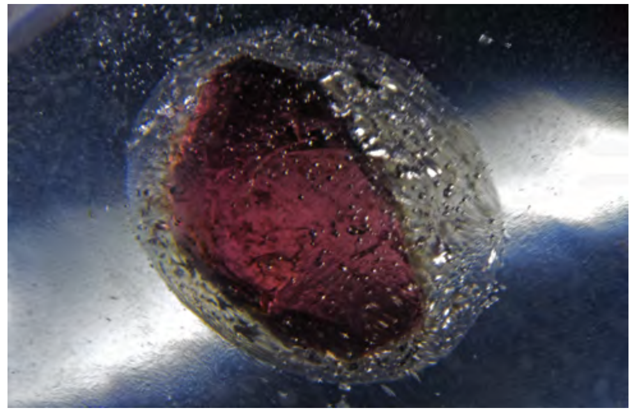


Figure 10. Gas bubbles can be seen in an otherwise nearly invisible glue layer between the quartz cabochons; these bubbles are abundant in the vicinity of the red garnet fragment. The fragment resides in a hollowed-out pocket and is surrounded with glue. Photomicrograph by Nathan Renfro; field of view 10.28 mm.

it is a relatively sharp fragment that resides in a pocket filled with glue (figure 10). The subtle glue layer between the cabochons becomes more apparent when viewed under UV light, which causes it to fluoresce chalky white; this fluorescence is stronger under long-wave than short-wave UV.

This specimen was purchased at the 2016 Tucson shows from a dealer specializing in inclusion specimens. The cabochon, part a collection of otherwise natural items, was fully disclosed as a man-made novelty. Its appearance in the marketplace represents an emerging trend that gemologists and collectors will see with increasing regularity as the fascination with inclusions grows (see the author's forthcoming article, "Evolution of the inclusion illusion," in the Summer 2016 *InColor*). Careful inspection with a loupe or microscope will in most cases reveal the underlying nature of this inclusion.

Elise A. Skalwold

Iridescent *Spondylus* Pearl

The optical phenomenon of iridescence is frequently observed in gem materials, but it is uncommon to see iridescent colors in porcelaneous pearls. Such pearls are appreciated for their prominent eye-visible flame structures, such as those seen in some Queen conch and Melo pearls. Pearls from these gastropods, along with *Spondylus* species bivalves, are routinely submitted to GIA's laboratory. A bluish reflective sheen is a common feature of the flames seen in *Spondylus* pearls (Fall 2014 Lab Notes, pp. 241–242; Winter 2015 Lab Notes, pp. 436–437).

A 6.97 ct bicolored white and pink *Spondylus* pearl (figure 11) was recently examined at GIA's Carlsbad labora-

Figure 11. This 6.97 ct bicolored white and pink Spondylus *pearl shows prominent reflective blue coloration over the fine parallel flame structure when viewed in certain directions under a single white light source. Photo by Robert Weldon/GIA.*

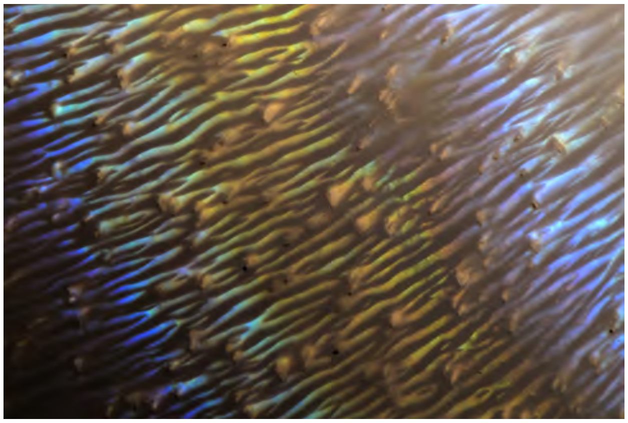


Figure 12. Under magnification and using fiber-optic illumination, iridescent colors ranging from purplish to dominant blue reflect from the fine, well-formed flame structure of this Spondylus *pearl. Photomicrograph by Artitaya Homkrajae; field of view 2.34 mm.*

Figure 13. The prominent sulfide inclusion in this 2.02 ct pyrope is clearly visible under the table facet. Photo by Kevin Schumacher.

tory. When a single white light was used to illuminate the pearl, a prominent reflective blue coloration over its fine parallel flame structure was visible on the white portions. This created a pseudo-chatoyant effect similar to other *Spondylus* pearls previously examined. What was particularly captivating about this pearl was that iridescent colors ranging from purplish to a dominant blue were seen on the fine, well-formed flame structure when a fiber-optic light was applied in certain directions (figure 12).

As with many gemstones and nacreous pearls, the spectral colors seen on the flame structure are the result of the interference effect of light reflecting off of structural features. In this case, the thickness of the aragonite lamellae permits white light to be diffracted into most of the visible light wavelengths, resulting in a colorful effect.

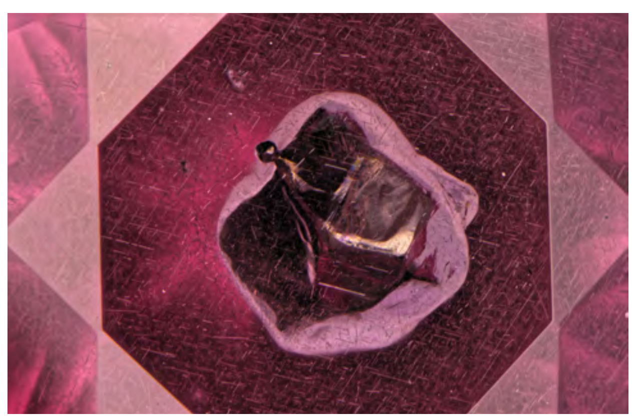
The iridescence characteristics of this pearl have not been encountered to such a marked degree in any other porcelaneous pearl examined by GIA.

Artitaya Homkrajae
GIA, Carlsbad

Metal Sulfide in Pyrope

The 2.02 ct "inclusion gem" shown in figure 13 is not only spectacular to inclusion enthusiasts, but also a scientific mystery. This vanadium- and chromium-bearing pyrope was cut from one of the samples featured in *G&G*'s Winter 2015 issue (Z. Sun et al., "Vanadium- and chromium-bearing pink pyrope garnet: Characterization and quantitative colorimetric analysis," pp. 348–369). The stone was faceted by Jason Doubrava (Poway, California) to display a relatively large, euhedral sulfide crystal inclusion. Sulfide crystals were observed in several of the samples in the 2015 study; the exact nature of the inclusions could not be determined by Raman analysis, but all displayed a metallic luster in surface-reflected light. Magnification also revealed a cloud of minute acicular inclusions resembling rutile surrounding the crystal (figure 14). Along with the elements expected for pyrope, such as Si, Al, Mg, Mn, and Fe, energy-dispersive X-ray fluorescence (EDXRF) analysis detected peaks for sulfur and rhodium. While sulfur would be expected in a metal sulfide, the rhodium peak is a mystery. Rhodium sulfide does exist, but explaining the presence of rhodium in this garnet would require destructive testing. In this case beauty trumps science, because this gem is truly a wonderful ad-

Figure 14. A cloud of extremely fine acicular inclusions in the pyrope surrounds the sulfide when viewed under the microscope with diffuse reflected light. Photomicrograph by Nathan Renfro; field of view 5.41 mm.



dition to the collection of this inclusionist and will thus remain a gemological curiosity.

John I. Koivula

Metallic Chromium Inclusions in Industrial By-Product Ruby

Technogenic corundum contained in metallurgical slag represents a potentially unique source of gem material. Since the 1950s, slags have been studied for their secondary uses. Their mineralogical and petrographic attributes have been documented, but to date there have been virtually no studies from a gemological standpoint.

X-ray powder diffraction analysis (XRD) was performed on two slag samples taken from the waste products of chromium ore processing by thermite reaction at a refinery located in Russia's Ural Mountains. These specimens showed the presence of corundum (α-Al_2O_3), the rare phase diaoyudaoite $NaAl_{11}O_{17}$, and a spinel-group mineral. For the spinel-group mineral, electron microprobe analysis (EPMA) indicated significant amounts of Mg, Cr, and Al. As seen in figure 15, the corundum contains transparent purplish red crystals up to 2.5 cm in length embedded in a diaoyudaoite matrix. The crystals may be elongated and prismatic, irregularly formed, or rounded. Gemological testing including refractometry, specific gravity measurements, and reaction under short-wave (254 nm) and long-wave (365 nm) UV. The UV reaction (figure 16, left) was consistent with natural and synthetic ruby (for in-depth analytical procedures and results, see E.S. Sorokina et. al., "On the question of technogenic ruby in the slags of Cr-V production," *Mine Surveying and Using of Mineral Resources,* Vol. 2, 2010, pp. 33–35, in Russian). Microscopic examination of the samples showed features such as gas bubbles and irregular growth lines, both of which are inconsistent with natural corundum. Most significant was the presence of a metallic-phase chromium that appeared in several forms, such as needles, dendrites, and rounded or irregularly formed black solid inclusions with metallic luster. The metallic chromium was most frequently observed along the ruby parting planes (figure 16, right); it is an inclusion that has never been detected in naturally occurring corundum or in any synthetic analogues.

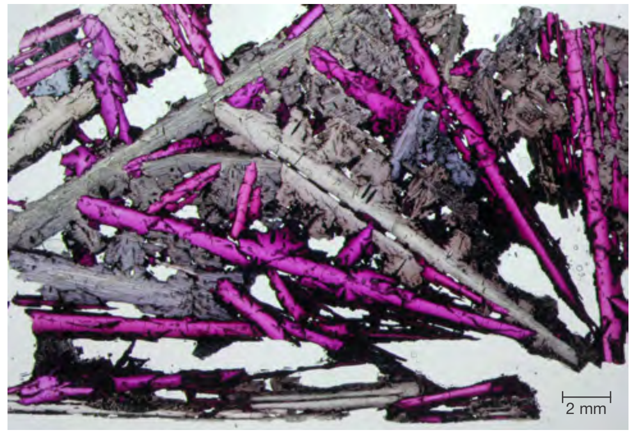


Figure 15. Photomicrograph of a petrographic thin section of ruby (purplish red)-diaoyudaoite (grayish green) slag, shown in transmitted light. From Sorokina et al. (2010).

Laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS) and EPMA showed high Cr content (4.3–7.7 wt.%), most likely linked to the capture of micron-sized metallic chromium inclusions during the measuring process. We also found 135–270 ppmw of Mg, 30–70 ppmw of Ti, and 5–10 ppmw of V. Fe, Ga, Ni, Pb, and

Figure 16. Left: Intense red photoluminescence typical of ruby observed under long-wave UV; field of view 8.34 mm. Right: Strongly reflecting rounded and irregularly shaped metallic chromium inclusions within the technogenic ruby, surrounded by greenish gray diaoyudaoite matrix. Shown in reflected light; field of view 0.288 mm. Photomicrographs by Elena S. Sorokina.

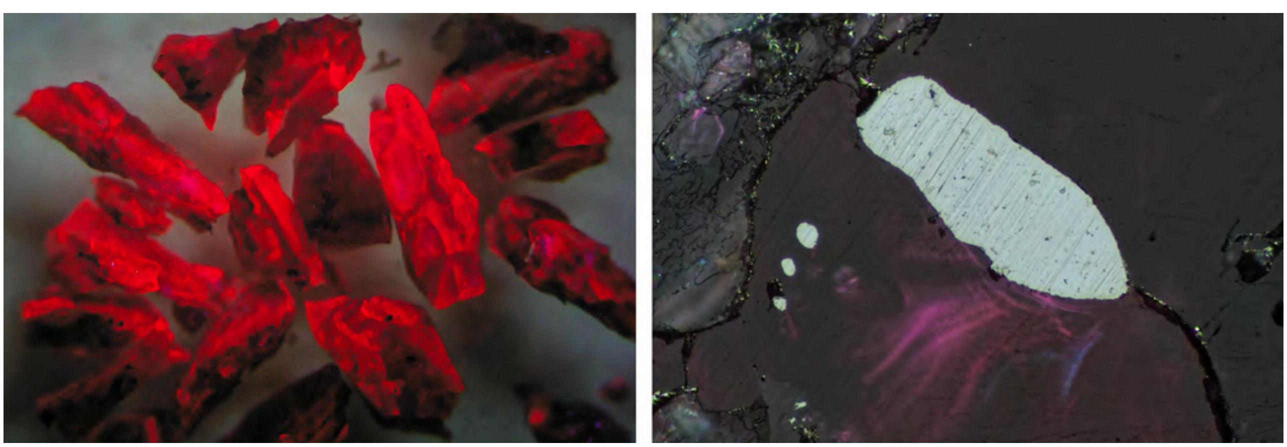


Figure 17. A pinkish orange inclusion dominates the interior of this 20.58 ct unpolished topaz crystal from Pakistan. Photograph by Kevin Schumacher.

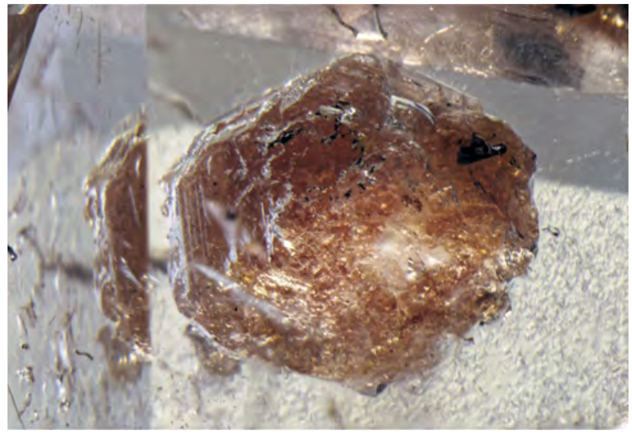


Figure 18. A combination of Raman and EDXRF analysis served to identify the inclusion as triplite. The inclusion is seen here using brightfield and fiber-optic illumination. Photomicrograph by Nathan Renfro; field of view 9.39 mm.

Pt were found to be below detection limit by both methods. This was the first time LA-ICP-MS had been applied to technogenic ruby.

The identification of metallic-phase chromium inclusions, coupled with trace-element chemistry, will serve to separate these ruby slag materials from natural and other artificial analogues.

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Quarterly Crystal: Triplite in Topaz

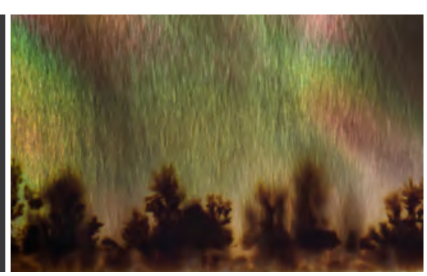
The transparent colorless 20.58 ct topaz crystal in figure 17 clearly hosts a prominent translucent pinkish orange inclusion. The topaz, from Biensa in Braldu Valley, Gilgit-Baltistan, Pakistan, was acquired from Dudley Blauwet of Mountain Minerals International (Louisville, Colorado). The bodycolor of the inclusion suggested that it might be either of two equally rare pegmatitic phosphates, triplite or väyrynenite, that are known to occur in pegmatites in that part of the world (figure 18).

Laser Raman microspectrometry was able to narrow the inclusion's identity to these two suspected phosphates. Triplite and väyrynenite have very similar Raman peak patterns, and the topaz host masked some of the significant peaks needed to conclusively separate the two minerals. Since triplite contains iron and väyrynenite does not, focused energy-dispersive X-ray fluorescence (EDXRF) analysis was used to examine the inclusion's chemical composition. Results indicated the presence of iron, identifying the inclusion as triplite. This marks the first time triplite has been reported as an inclusion in topaz.

John I. Koivula

For More on Micro-World

To watch a video of the aurora-like scene in the carved iris agate featured in this section, please visit http://www.gia.edu/gems-gemology/aurora-iris-agate-carving, or scan the QR code on the right.



G&G

Gem News International

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COLORED STONES AND ORGANIC MATERIALS

Kämmererite cabochons from India. Kämmererite is a purple variety of clinochlore, a mica-like Mg-Al-silicate with the formula $(Mg,Fe)_5Al[(OH)_8|AlSi_3O_{10}]$. Its color is caused by chromium. Kämmererite is always found in fractures of ultrabasic rocks, usually with chromite ore. The only known locality for transparent crystals is the Kop Krom chromite mine in the Kop Daglari Mountains of Turkey. Transparent crystals from this area (figure 1) can measure up to 2 cm. Some of this material has been faceted as rare collector gemstones (H. Bank and H. Rodewald, "Schleifwürdiger, roter, durchsichtiger Chlorit: Kämmererit," *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, Vol. 28, No. 1, 1979, 39–40, in German).

An unknown location in India recently yielded massive kämmererite that was used to carve interesting cabochons (figure 2); 10 such samples were examined in this study. The cabochons have an attractive light to dark purple color; some thinner pieces are translucent. Some of the material shows a folded texture, and this type is visually similar to charoite, a well-known ornamental stone from Siberia. The measured refractive index (RI) of the new kämmererite is approximately 1.57, very close to charoite, but clinochlore has a much lower Mohs hardness (about 2.5, rather than charoite's 5–6). This new kämmererite is inert under UV light, but white layers in the samples show creamy fluorescence under both long-wave and short-wave UV. Raman spectroscopy revealed a characteristic group of peaks at 3877, 4063, 4175, 4500, and 4920 cm^{-1} in the spectrum (figure 3), confirming the material's identity. Visible spectra further supported this conclusion. The amount of

Figure 1. This 57 mm wide kämmererite rough and 0.57 ct faceted stone are from the Kop Daglari Mountains of Turkey. Photo by Jaroslav Hyršl.

Figure 2. These kämmererite cabochons, with widths of 27 mm and 21 mm, are from an undisclosed location in India. Photo by Jaroslav Hyršl.

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

Gems & Gemology, Vol. 52, No. 2, pp. 206–220.

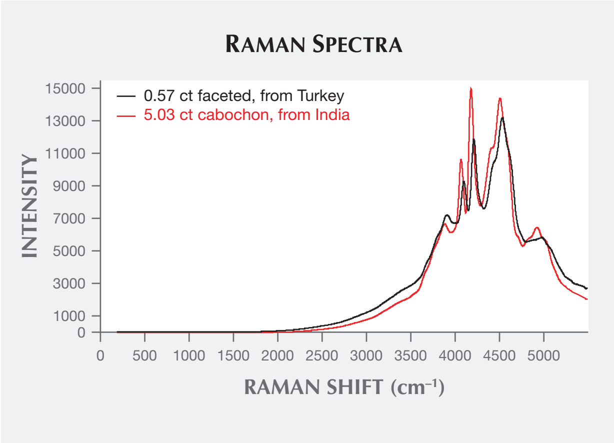


Figure 3. Raman spectra showing characteristic peaks of kämmererite at 3877, 4063, 4175, 4500, and 4920 cm^{-1}.

new massive kämmererite rough is unknown, and the material may remain rare.

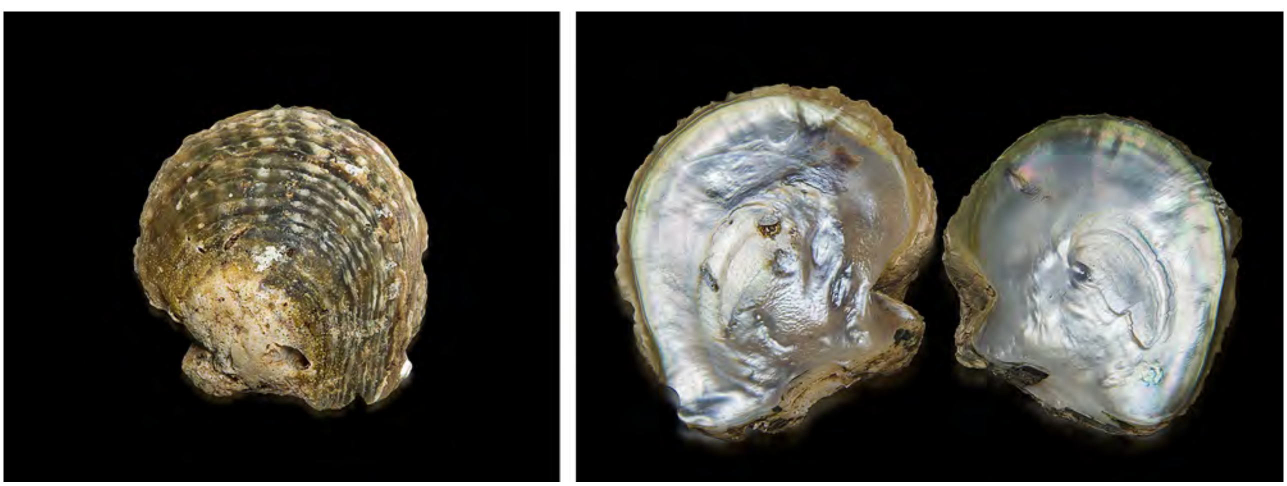
Jaroslav Hyršl (hyrsl@hotmail.com)
Prague

Spectral characteristics of *Pinctada mazatlanica* and *Pinctada margaritifera* pearl oyster species. *Pinctada margaritifera* is a well-known mollusk species of the Indo-Pacific region that produces gray to black pearls. Cultured pearls from the mollusk are often referred to as "Tahitian" in the market. Both natural and cultured *P. margaritifera* pearls are noted for their characteristic UV-visible spectra. The typical reflectance feature at 700 nm is a key identification attribute for this species (K. Wada, "Spectral characteristics of pearls," *Gemmological Society of Japan,* Vol. 10, No. 4, 1983, pp. 3–11, in Japanese).

Pinctada mazatlanica, the so-called Panamanian pearl oyster, is a species closely related with *P. margaritifera*. Although *P. mazatlanica* was originally classified as a subspecies of *P. margaritifera* (R.L. Cunha et al., "Evolutionary patterns in pearl oysters of the genus Pinctada (Bivalvia: Pteriidae)," *Marine Biotechnology,* Vol. 3, No. 2, 2011, pp. 181–192), in 1961, the taxonomy of the Pinctada genus was revised, and *P. mazatlanica* was listed as a distinct species due to different shell characteristics and geographical occurrence. *P. mazatlanica* is extensively distributed along the western coast of the Americas from Mexico to Peru and around the Galapagos Islands. It is considered a native pearl oyster species of the Gulf of California in Mexico and around the Archipelago de las Perlas in the Gulf of Panama (G.F. Kunz and C.H. Stevenson, *The Book of the Pearl*, The Century Co., New York, 1908, p. 69). The spectroscopic characteristics of this species were believed to be similar to *P. margaritifera* (Winter 2005 Lab Notes, p. 347), yet this author was unable to find any recorded spectra in the literature.

GIA's Bangkok laboratory recently studied three *P. mazatlanica* shells from Mexico (two are shown in figure 4). These shells appeared to have morphology between *P. maxima* and *P. margaritifera* mollusks (P. C. Southgate and J.S. Lucas, *The Pearl Oyster,* Elsevier, Oxford, 2008, p. 60). The rounded outlines were similar to those of *P. maxima*; in each, the shell's height was almost equal to the width. The color of the outer surfaces alternated from yellowish brown to dark greenish gray, with rays of whitish blotches

Figure 4. These Pinctada mazatlanica *shells were obtained from Mexico. Left: The shell has a rounded outline, with a nearly equal height and width. The exterior surface exhibits alternating yellowish brown and dark greenish gray colors, with whitish blotches fanning out from the center. Right: The interior view of the shell on the left alongside a smaller example showing a yellowish green nacreous rim with a distinct orient. Photos by Lhapsin Nillapat.*



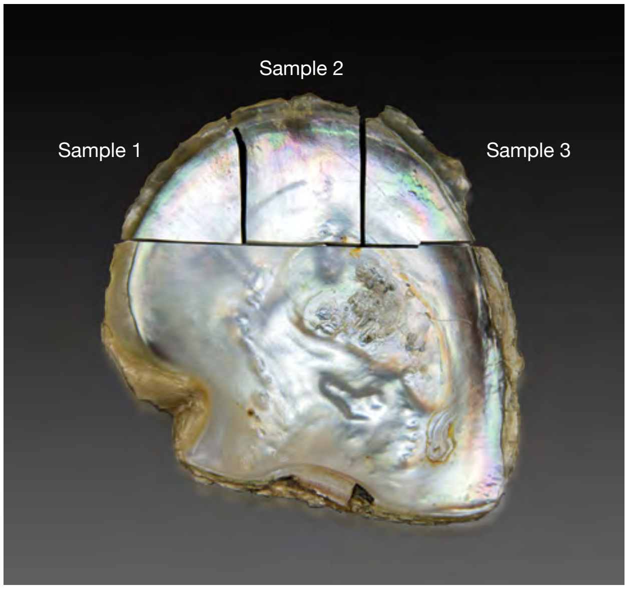


Figure 5. The lip area of one P. mazatlanica *shell was cut into three pieces to investigate the reflectance spectral characteristics in the dark and light nacreous areas. Photo by Lhapsin Nillapat.*

fanning out from the center. The inner nacreous rims ranged from yellowish green to dark gray with visibly iridescent overtones resembling *P. margaritifera*. To investigate reflectance UV-visible spectral characteristics in the dark and light nacreous areas, three pieces were cut from one of the shells (figure 5).

The dark gray nacre of all the samples exhibited the same spectral pattern as those recorded from naturally colored gray to black nacre of *P. margaritifera* shells and pearls. The reflectance feature at 700 nm was consistently present in these samples, together with a uroporphyrin feature at 405 nm (figure 6). Uroporphyrin has been established as one type of pigmentation responsible for gray to black tones in some pearl oyster species (Y. Iwahashi and S. Akamatsu, "Porphyrin pigment in black-lip pearls and its application to pearl identification," *Fisheries Science*, Vol. 60, No. 1, 1994, pp. 69–71). However, the feature at 495 nm that is often displayed in natural dark-colored nacre from *P. margaritifera* was not present in these samples, while the spectra collected in white to silver areas lacked the 405 and 700 nm characteristics. The spectra were relatively featureless, with no significant reflectance showing in the visible region. This was in keeping with results obtained from the white to silver nacre of *P. maxima* and *P. margaritifera* shells and pearls (S. Elen, "Identification of yellow cultured pearls from the black-lipped oyster *Pinctada margaritifera*," Spring 2002 *G&G*, pp. 66–72).

Further studies at GIA's New York laboratory on *P. mazatlanica* shells from GIA's Carlsbad collection confirmed these findings. Additionally, the yellow-green nacre close to the dark gray nacreous rim of the shell showed a broad trough from 330 to 460 nm. This consisted of features between 330 and 385 nm and between 385 and 460 nm. A clear feature at 700 nm was observed, but the one at 405 nm was not evident. The spectra are comparable with natural yellow *P. margaritifera* nacre samples (again, see Elen, 2002).

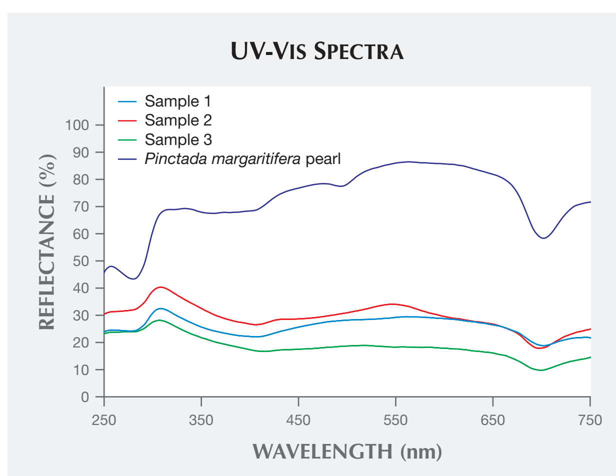
Photoluminescence (PL) spectra collected on the dark gray and yellow-green nacreous areas of all the samples showed bands at approximately 620, 650, and 680 nm. These same PL bands are observed in naturally colored nacre of *P. margaritifera* and *Pteria sterna*, as well as several colors of *P. maxima* nacre (S. Karampelas, "Spectral characteristics of natural-color saltwater cultured pearls from *Pinctada maxima*," Fall 2012 *G&G*, pp. 193–197).

The reflectance and PL spectra from our samples prove the close relationship between *P. mazatlanica* and *P. margaritifera*. Pearls produced by these two black-lipped oyster species therefore share similar spectral characteristics.

Artitaya Homkrajae
GIA, Carlsbad

Macedonian ruby specimens. The Macedonian town of Prilep has been a source of marble since antiquity, even supplying some Roman settlements. Rubies have occasionally been found within the Bianco Sivec quarry, according to gem dealer Denis Gravier (Gravier & Gemmes, Poncin, France). Although Prilep is mainland Europe's only known natural ruby source, only in the past 15 years has there

Figure 6. UV-visible reflectance spectra of the darker gray nacre areas of all three P. mazatlanica *shell samples shown in figure 5 are similar to the spectrum from a* P. margaritifera *pearl. All show a uroporphyrin feature at 405 nm and a feature at 700 nm, which is diagnostic of* P. margaritifera. *These spectra prove the similar spectral characteristics between* P. mazatlanica *and* P. margaritifera.



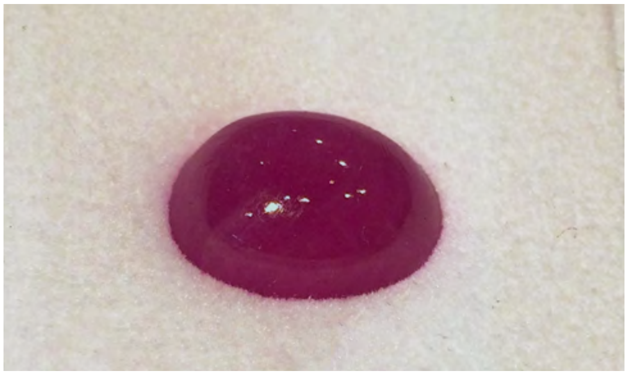


Figure 7. This 9.93 ct ruby cabochon from Macedonia was seen at the Jewellery & Gem Fair – Europe in Freiburg, Germany. Photo by Russell Shor/GIA.

been an effort to mine the gems. Gravier offered several rubies from the Prilep quarry at the March 19–22 Jewellery & Gem Fair – Europe in Freiburg, Germany, including the 9.93 ct cabochon seen in figure 7. None of the specimens were faceted. Gravier said the deposit produces comparatively few gem-quality rubies, and most are too cloudy for faceting. The best ones have a distinct "raspberry" color. It is unknown whether any of the material is heat treated. Macedonian craftsmen have developed a local industry using these rubies in jewelry and *objets d'art*.

Russell Shor
GIA, Carlsbad

Multiphase fluid inclusions in blue sapphires from the Ilmen Mountains, southern Urals. Most gem-quality sapphires are found in placers that originate from the weathering of primary deposits. Discovering a mineral *in situ*, or within the host rocks, is rare. In August 2015, some of the authors visited a corundum deposit in the Ilmen Mountains in the southern Urals of Russia (figure 8) to collect the stones *in situ* for research. This is a primary source where blue sapphire megacrysts are found exclusively in syenite pegmatites. The occurrence is located inside the Ilmen State Reserve, and its commercial exploitation is forbidden.

Figure 8. Map showing the location of the blue sapphire occurrence within Russia.

Figure 9. Sapphire crystals in feldspar matrix of a syenite pegmatite from the Ilmen Mountains of Russia. The largest sapphire crystal measures 5.9 × 4.2 cm. From a private collection; photo by Elena S. Sorokina.

Corundum syenite pegmatites in the Ilmen Mountains present an REE-rich source of transparent to translucent blue sapphire crystals measuring up to 5.9 × 4.2 cm (figure 9). But the brittle deformation throughout the gem-bearing rocks, which appears to be linked to syntectonic and post-tectonic processes that occurred at the deposit and the surrounding area, increased the amount of fissures in the corundum. As a result, the sapphires are of a lower quality and can only be faceted into small stones. Six sapphire wafers and nine petrographic thin sections of mineral from corundum-bearing rocks of this occurrence were recently examined at GIA's Carlsbad lab.

Laser ablation–inductively couple plasma–mass spectrometry (LA-ICP-MS) and electron microprobe analysis (EPMA) indicated medium-rich Fe (2470–3620 ppmw), high Ga (190–280 ppmw), and low Mg (3–9 ppmw) with Ga/Mg > 29, all in the range of magmatic sapphires (see J.J. Peucat et al., "Ga/Mg ratio as a new geochemical tool to differentiate magmatic from metamorphic blue sapphires," *Lithos*, Vol. 98, No. 1–4, 2007, pp. 261–274).

Ferrocolumbite, zircon, and alkali feldspar group minerals, identified by confocal micro-Raman spectroscopy, were observed as syngenetic inclusions. Epigenetic muscovite and exsolved needles (most likely ilmenite) were found as well; along with syngenetic inclusions, they are

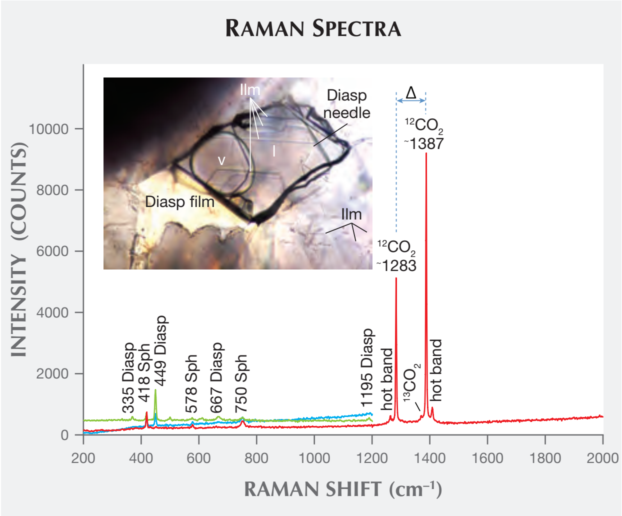


Figure 10. Raman spectra at room temperature of a fluid inclusion trapped in a sapphire from the Ilmen Mountains: $^{12}CO_2$ Fermi doublet along with hot bands and $^{13}CO_2$ peak (red trace), diaspore needle (blue), and a diaspore thin film (green). For $^{12}CO_2$, the average distance between Fermi doublet peaks (Δ) was calculated as 104.25 cm^{-1}. Diasp = diaspore, Sph = sapphire, Ilm = ilmenite, l = liquid CO_2, v = vapor CO_2. Photomicrograph by Elena S. Sorokina; polarized transmitted light, field of view 0.288 mm.

common phases in mineral assemblages of Ilmen corundum syenite pegmatites (see V. F. Zhdanov et al., "The mineralogy of corundum pegmatite pit no. 298 of the Ilmen State Reserve," *Materialy k mineralogii Yuzhnogo Urala* [*Materials to Mineralogy of South Urals]*, AS USSR, 1978, pp. 92–97, in Russian). Wafers 200–400 μm in width were prepared in order to study fluid inclusions (FI) trapped within the sapphire crystals.

Using Raman spectroscopy, solid phases in needle and thin-film form were identified as diaspore (figure 10); both vapor and liquid phases were found to be CO_2, with a Fermi doublet for the liquid phase at 1282.9–1283.2 and 1387.2–1387.6 cm^{-1}, accompanied by less intense symmetrical bands ("hot bands"; see N.B. Colthup et al., *Introduction to Infrared and Raman Spectroscopy*, 2nd ed., Academic Press, New York, 1975) at approximately 1264 and 1408 cm^{-1} and a small band at 1370 cm^{-1} due to $^{13}CO_2$. Raman spectra in the 2000–4000 cm^{-1} range did not show H_2O-, CH_4-, or N_2-related bands. The less intense apparent maxima at 418, 578, and 750 cm^{-1} belong to sapphire vibration modes. The distance between Fermi doublet peaks (Δ) ranged from 104.1 to 104.4 cm^{-1} (again, see figure 10), occurring at about 0.7 g/cm^3 CO_2 density (see X. Wang et al., "Raman spectroscopic measurements of CO_2 density: Experimental calibration with high-pressure optical cell (HPOC) and fused silica capillary capsule (FSCC) with application to fluid inclusion observations," *Geochimica et Cosmochimica Acta*, Vol. 75, 2011, pp. 4080–4093). The distance was linked to the pressure at approximately 1.8 kbar for the trapping of fluid inclusions within the sapphire matrix (CO_2 P-T *isochores*, or lines of constant density). The CO_2 homogenization temperature (the temperature at which the fluid inclusion becomes a single-phase liquid or vapor) occurred in the liquid phase and measured between 30.1° and 30.7°C (figure 11), while the corundum-diaspore equilibrium was estimated at 510°–530°C (matching the previous estimation by V.A. Simonov, *Usloviya mineraloobrazovaniya v granitnykh peg-*

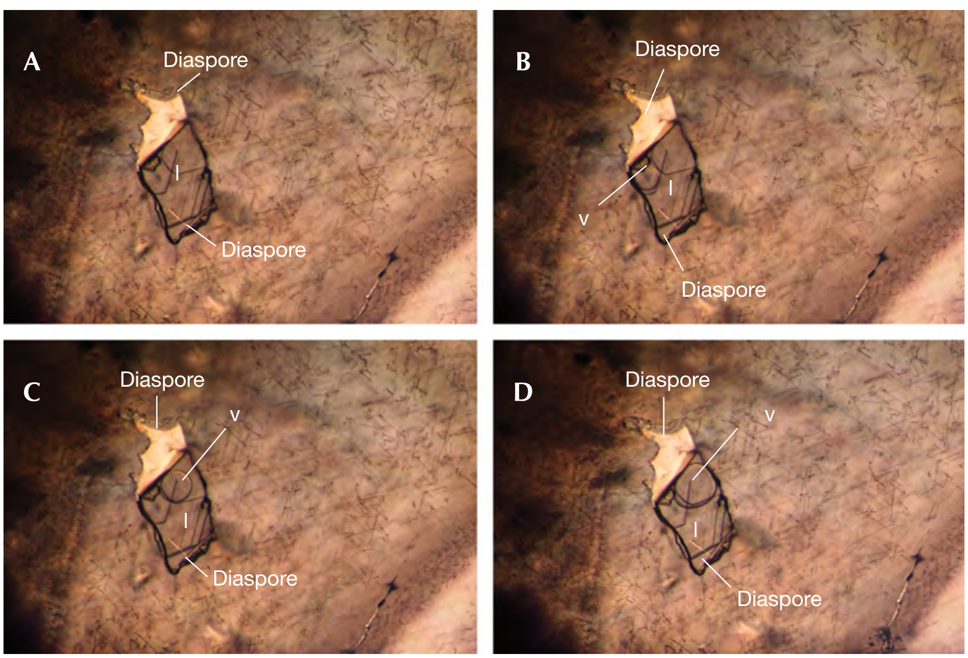


Figure 11. Homogenization of CO_2 in a fluid inclusion in sapphire from the Ilmen Mountains occurs in the liquid phase between 30.1° and 30.7°C. A: Homogenization of CO_2 above 30.7°C. B and C: Vaporization of CO_2 with a temperature below 30.7–30.1°C. D: The multiphase FI at room temperature. l = liquid, v = vapor. Photomicrographs by Jonathan Muyal; transmitted polarized illumination, field of view 0.72 mm.

matitakh [*Conditions of Mineral Formation in Non-Granitic Pegmatites*], Nauka, Novosibirsk, USSR, 1981, in Russian). Based on the determined pressure (around 1.8 kbar), the temperature of stability for the corundum-orthoclase-H_2O system was higher than 690°C (H.S. Yoder and H.P. Eugster, "Synthetic and natural muscovites," *Geochimica et Cosmochimica Acta*, Vol. 8, 1955, pp. 225–280), likely linked to the multistage geological history of blue sapphire crystallization along the P-T path in the Ilmen Mountains.

Further study of these sapphires is needed to better understand the geological history of this locality, but the information obtained can provide valuable clues about the characterization of gem corundum from secondary placers.

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Tremolite and diopside bead with unusual texture and color. In recent years, Buddhist prayer beads have become increasingly popular in Chinese jewelry. These beads are made into a variety of shapes from many kinds of gem materials.

At the 2015 China International Jewelry Fair in Beijing, a barrel-shaped bead with unusual green and white color (figure 12) attracted our interest. The bead weighed 6.39 g and measured approximately 30.5 × 10.8 × 10.5 mm. The hydrostatic specific gravity (SG) was 3.05, but it was difficult to obtain individual spot RIs from the white and green areas. The entire sample was inert to both long-wave and short-wave UV. The infrared reflectance spectrum (figure 13) of the whitish mineral indicated tremolite, with characteristic peaks at 1093, 988, 902, 743, 676, 529, and 470 cm^{-1}, while the greenish mineral's spectrum matched that of diopside, with peaks at 1060, 979, 921, 681, 511, and 410 cm^{-1}.

Figure 12. This 6.39 gram barrel-shaped bead was unusual for its texture and color. Photo by Yanjun Song.

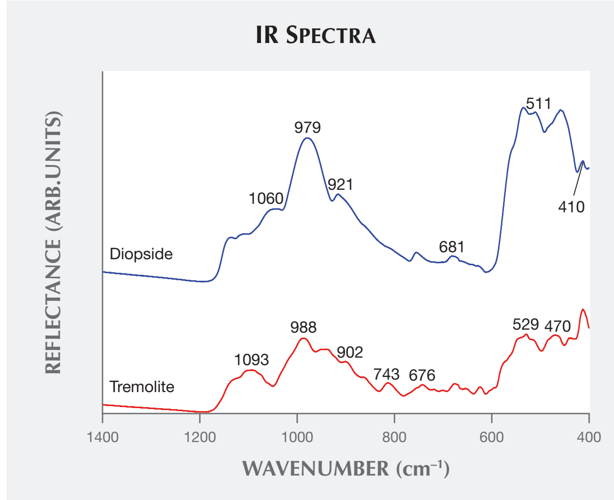

Figure 13. IR spectroscopy identified the whitish mineral in the bead as tremolite (red trace, peaks at 1093, 988, 902, 743, 676, 529, and 470 cm^{-1}) and the greenish one as diopside (blue trace, peaks at 1060, 979, 921, 681, 511, and 410 cm^{-1}). The spectra are offset for clarity.

Raman spectra of the white and green areas (figure 14) were obtained using 785 and 532 nm laser excitation, respectively. Peaks at about 1058, 1028, 754, 673, 394, and 224 cm^{-1} indicated tremolite, while those at 1013, 667, 559, 393, and 326 cm^{-1} were consistent with diopside.

Tremolite and diopside are common gem materials in the jewelry trade. Both occur in nephrite, where tremolite is the main mineral and diopside is an accessory mineral. This was the first time we had encountered diopside rather than tremolite as the major mineral when both occurred within the same sample.

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SYNTHETICS

Synthetic moissanite imitations of synthetic colored diamonds. Three faceted specimens were recently submitted to the Earth Science and Resources College of Chang'an

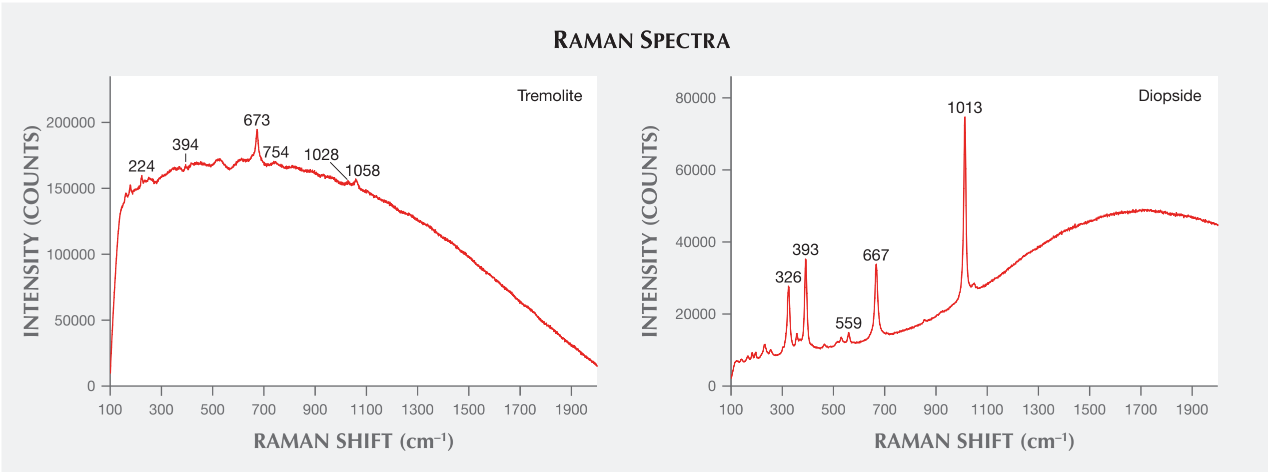


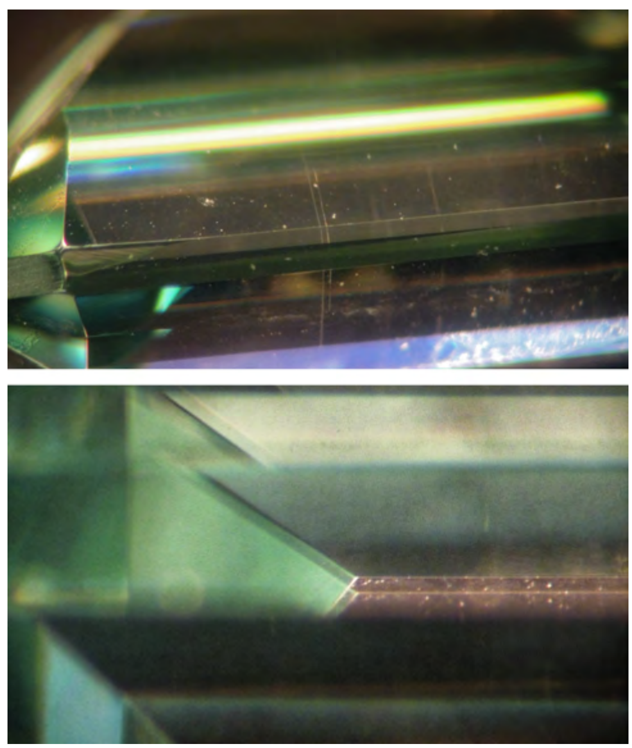
Figure 14. Raman spectra of the barrel-shaped bead. Left: Peaks at 224. 394, 673, 754, 1028, and 1058 cm^{-1} were indicative of tremolite. Right: Peaks at 326, 393, 559, 667, and 1013 cm^{-1} were consistent with diopside.

University by a client who acquired them as synthetic colored diamonds (figure 15). All three specimens were relatively clean to the unaided eye. The RI of the specimens was over the limit of the gem refractometer. The average hydrostatic SG value was 3.21, and all samples were inert under long-wave and short-wave UV radiation. Microscopic examination revealed clear doubling of numerous stringers and some needle-like inclusions (figure 16). All of these features were consistent with synthetic moissanite (K. Nassau et al., "Synthetic moissanite: A new diamond substitute," Winter 1997 *G&G*, pp. 260–275). Raman spectra of the samples were obtained using 785 nm laser excitation from three different orientations: parallel to the c-axis, perpendicular to the c-axis, and random orientation (one specimen's spectra is shown in figure 17). Results for all three samples indicated synthetic moissanite, with the peaks at 149, 767, 789, and 967 cm^{-1} obtained from the random orientation (see rruff.info).

Figure 15. Submitted as synthetic diamonds, the 0.99 ct blue-green emerald step cut (left), 0.85 ct brown-yellow standard round brilliant (center), and 1.90 ct deep green standard round brilliant (right) were all identified as synthetic moissanite. Photo by Yanjun Song.

Moissanite (silicon carbide, or SiC) has many polytype structures, including cubic (C), hexagonal (H), and rhom-

Figure 16. Needle-like inclusions (top) and doubling of numerous stringers (bottom) are shown here in the emerald step cut. Photomicrographs by Yanjun Song; field of view 4.22 mm (top) and 2.26 mm (bottom).



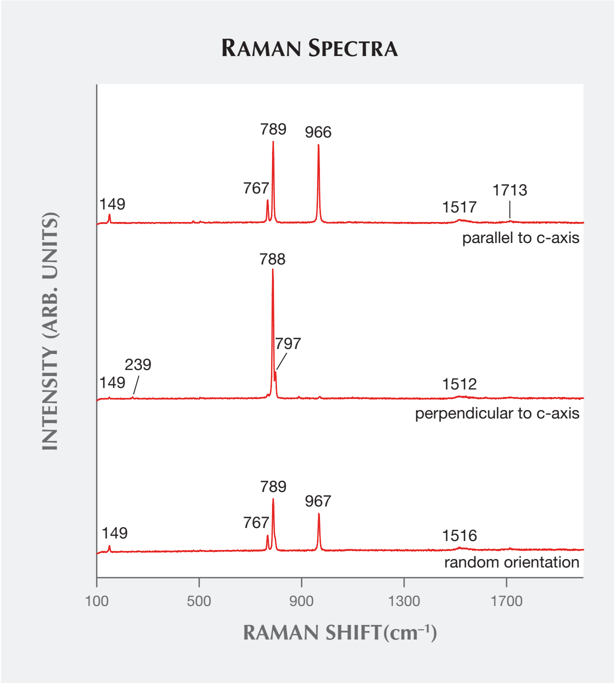


Figure 17. Raman analysis of the emerald step cut from three different optical orientations, using a near-infrared wavelength of 785 nm, confirmed its identity as synthetic moissanite.

bohedral (R). Hexagonal structure 4H-SiC and 6H-SiC (space group P63mc) are the most common polytypes used as gem material. In this study, the characteristic peaks at 149, 767, 789, and 966 cm^{-1}, obtained from the orientation parallel to the c-axis, were consistent with those previously reported for 6H-SiC (S. Nakashima and H. Harima, "Raman investigation of SiC polytypes," *Physica Status Solidi A*, Vol. 162, No. 1, 1997, pp. 39–64).

High-quality colorless and black synthetic moissanites are common diamond imitations in the jewelry trade. As the growth techniques of synthetic moissanite continue to improve and the popularity of fancy-color diamonds increases in the Chinese market, we anticipate that high-quality synthetic colored moissanite will become more prevalent.

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TREATMENTS

Steam-dyed amber. "Beeswax" amber, a common trade name used in the Chinese gem market, refers to yellow amber that has a semitranslucent, opalescent, milky appearance with greasy luster. Among the beeswax ambers, "chicken-fat yellow beeswax" is very popular for its bright color. Global production is limited, and the material is in high demand in the Chinese amber market. Therefore, many methods to enhance the color of beeswax amber have been attempted. In March 2016, the Guangzhou laboratory of the Gem Testing Center, China University of Geosciences (Wuhan) received four pieces of chicken-fat yellow beeswax amber samples from two different clients (figure 18); two more pieces were received in May from an unrelated owner (figure 19).

Infrared spectroscopy showed all ambers with typical "Baltic shoulder" patterns in the 1100–1300 cm^{-1} range, with low and broad bands in higher frequencies and a high, sharp peak at 1160 cm^{-1}. Instead of the whitish yellow of natural Baltic ambers, we saw either bright yellow or orange hues, both of which are unusual. Under strong transmitted light, the yellow color of the round bead in figure 18 (left) showed a mottled distribution, which was proof of

Figure 18. Left: This "chicken-fat yellow beeswax" amber bead, approximately 15 mm in diameter, was treated by the steam dyeing method. Right: The unusually dark orange color of these pear-shaped samples comes from steam dyeing. Photos by Fen Liu.

Figure 19. The two bright yellow beads in the center, 8 mm and 9 mm in diameter, were treated by steam dyeing, while the bracelet contains natural-color amber. Photo by Jiewan Huang.

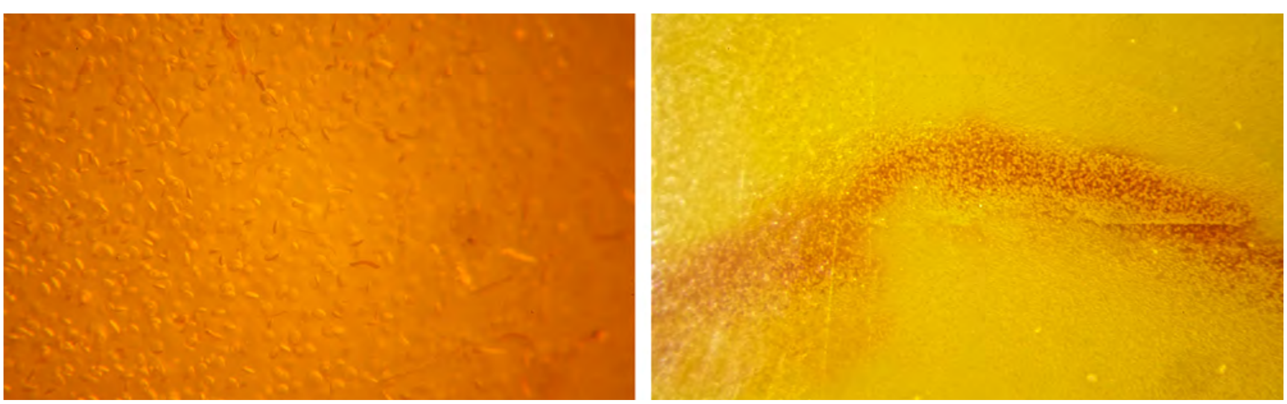
Figure 20. The darker mottled color patches in this sample indicate that the bead was unevenly dyed. Photo by Fen Liu.

uneven dyeing (figure 20); however, microscopic examination revealed small squashed bubbles caused by "steam treatment." Further, red color filaments unrelated to the cracks among the bubbles near the surface were traces of residual dyes (figure 21, left).

The color of the pear-shaped samples appeared to be darker than the yellow associated with chicken-fat amber (again, see figure 18, right). This darker color faded slightly when the surface was swabbed with alcohol. Under 40× magnification, the bubbles appear to have yellow menisces. The bubble-rich regions were darker than the portions with fewer bubbles. In some areas among the bubbles, an abnormal dark orange color zone appeared to be induced by residual color matter (figure 21, right). All these observations indicated the amber pieces underwent some artificial treatment. The clients admitted that these beeswax ambers were treated by a new treatment method, called "steam dyeing," which delivers gas bubbles from colored water into the amber structure at pressure and temperature conditions close to those of saturated water vapors.

Steam dyeing treatment is easy to miss. The rapid development in amber treatment methods means that con-

Figure 21. Left: The squashed bubbles are induced by steam treatment, and the red filaments are possible traces of residual dye. Photomicrograph by Fen Liu; field of view 2.95 mm. Right: The dark orange color zone among the bubbles, unrelated to the cracks, indicates that the color zone was introduced by dyeing. Photomicrograph by Shufang Nie; field of view 2.95 mm.



sumers and laboratories must be cautious when dealing with these "chicken-fat yellow beeswax" ambers.

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Polymer-coated serpentine. Jadeite, nephrite, serpentine, chalcedony, and quartzite were all referred to as "jade" in ancient China, where objects were defined by their craftsmanship rather than the materials themselves. The term is still widely used in the Chinese market for many types of materials. "Xiuyan jade" is actually a form of serpentine, so named for Xiuyan, a city in China's Liaoning province where serpentine deposits are abundant.

The pendant in figure 22 was submitted to the Lai Tai-An Gem Laboratory by a client who claimed the material was jadeite jade. The pendant, which weighed 222.03 ct and measured 58 × 37 × 17 mm, showed a light green carved fish on a brown and yellow background. At first glance, it appeared to display a plastic-like luster.

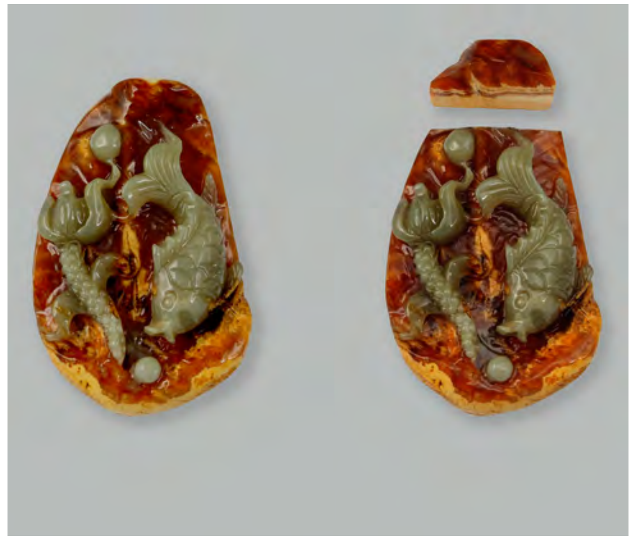

Figure 22. The serpentine pendant before and after cutting. Photos by Lai Tai-An Gem Lab.

Identical spot RIs of 1.56 were obtained from two different parts of the object, and an SG of 2.40 was determined. Both measurements were lower than expected for jadeite. The SG may have been affected by a polymer coating; this was partially confirmed when bubbles were observed on some surface areas under magnification. Microscopic observation proved that the piece was solid and not assembled. It was inert under long-wave and short-wave UV light from an ultraviolet viewing cabinet, whereas most polymer-coated objects show weak to strong reactions. The client granted permission to cut the piece in two for further analysis.

DiamondView observations of the cross section revealed an inert reaction from the object's interior, but the coatings on the surface produced a strong bluish fluorescence (figure 23). FTIR spectroscopy on the interior identified the material as serpentine, but peaks at 3060, 3025, 2932, and 2858 cm^{-1}, obtained from the surface, showed that a polymer was present. Peaks at 1045, 673, 564, and 485 cm^{-1}, detected from both the interior and the surface, were indicative of serpentine (figure 24); this was confirmed by Raman spectroscopy.

Coatings are normally applied to gem materials to improve luster and, in some cases, provide a degree of stability. This was the first case of coated serpentine we have encountered. Care should be taken to identify such coatings; the simplest way to detect the treatment is to check for any unusual reaction under the ultraviolet viewing cabinet, but in this case, the UV reaction only showed in the ultra-short-wave UV of the DiamondView. Serpentine's characteristically low hardness makes it a very suitable carving material, but any treatments applied to it should be fully disclosed.

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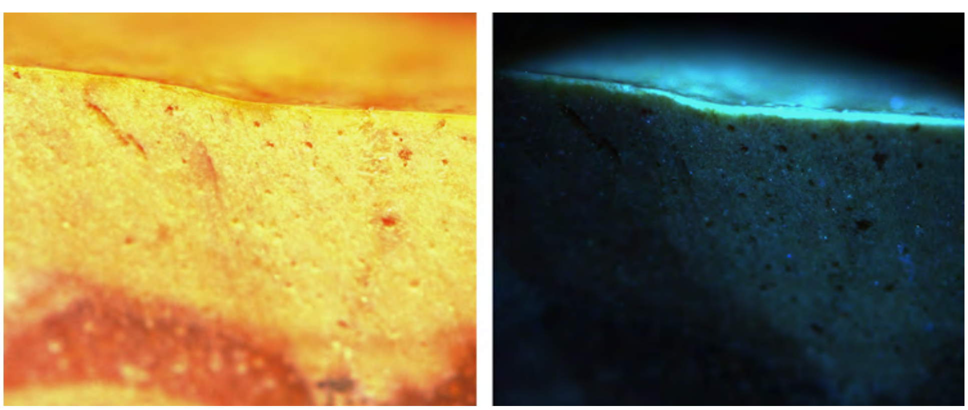

Figure 23. DiamondView imaging showed that the inner portion of the serpentine was inert, while the surface exhibited a strong bluish fluorescence. These images show the reflection from the polymer-coated surface in visible (left) and UV light (right). Images by Lai Tai-An Gem Lab.

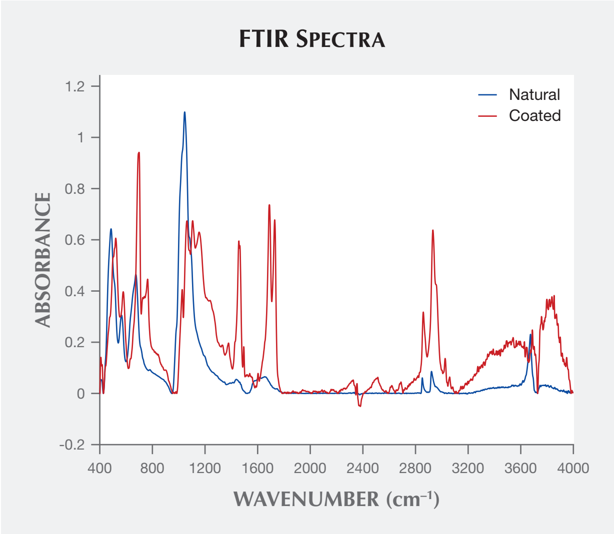

Figure 24. FTIR spectroscopy revealed peaks indicative of coating at 2858, 2932, 3025, and 3060 cm^{-1} (red) and serpentine peaks at 485, 564, 673, and 1045 cm^{-1} (blue).

Figure 25. Jason Baskin is seen holding his largest almandine in graphite schist specimen at the 2014 Springfield Mineral Show. This specimen is now part of the collection of the Mineralogical and Geological Museum at Harvard University. Photo courtesy of Jay's Minerals.

MORE FROM TUCSON

Almandine in graphite schist specimens. At this year's Tucson shows, the authors saw the breathtaking almandine-pyrope in graphite schist specimens that debuted at the August 2014 East Coast Gem, Mineral, and Fossil Show in Springfield, Massachusetts (figure 25). Mine owner Jason Baskin (Jay's Minerals, Flemington, New Jersey) first encountered the material from the Red Embers mine (then called the Two Fat Guys mine) in Franklin County, Massachusetts, in the early 2000s, and his family bought the mineral rights to this property in 2008. Mr. Baskin, along with his cousin Kyle Baskin and uncle Kevin Baskin, worked the mine (currently closed to the public) by hand, with tools such as chisels and hammers, for six years before unveiling these specimens and the location of the mine (figure 26).

Good-quality almandine specimens are found in various localities in the eastern United States. This deposit is located in a metamorphosed zone full of layered graphite schist. According to Mr. Baskin, the thickness of the veins can vary from about 1 to 6 feet wide. Black columnar accompanying minerals can be found in the graphite matrix in between the garnet crystals on some specimens (figure 27). This long needle-like mineral was identified as dravite tourmaline. Based on his many years of mining experience at this location, Mr. Baskin says that the garnet crystals tend to have higher quality when they occur within a fold. Some of the garnet crystals are suitable for faceting, but it is the specimens that generate the most purchases. The largest crystal found to date is 28 mm in diameter; the largest faceted stone is 4.7 ct.

These striking specimens displayed sharp, dark red trapezohedra in fine-grained silvery graphitic schist (R.B.

Figure 26. Jason Baskin displays two giant pieces of graphite schist extracted from the mine. Hand tools such as the sledgehammer behind him are used to mine the specimens. Photo courtesy of Jay's Minerals.

Figure 27. With a strong light source behind the specimen, the garnet crystals within the graphite glow, showing an attractive burgundy color. The black columnar mineral in the graphite matrix was identified as dravite. Not all specimens contain dravite, though its presence adds charm to the piece. Photo courtesy of Jay's Minerals.

Cook, "Almandine New York City, New York County, New York State," *Rocks & Minerals*, Vol. 84, No. 3, 2009, pp. 244–252). In a previously published article, Raman spectroscopy identified the garnet as predominantly almandine with some spessartine and minor pyrope components (C. Williams and B. Williams, "Almandine from Erving, Massachusetts," *Journal of Gemmology*, Vol. 34, No. 4, 2014, pp. 286–287). Most specimens have multiple garnet crystals embedded in them, with the largest containing more than 100 crystals.

Due to the fine-grained nature of the host rock, a dust mask must be worn during the mining process. The most attractive aspect of these specimens is the exposure of the garnet crystals from both sides of the rock, which allows the light to travel through and make the garnet glow, showing its deep burgundy color (again, see figure 27). To achieve this goal, Baskin has tried numerous abrasives to remove the schist on both sides of the garnet without affecting the crystals' surfaces. Some of the experimental abrasives included various kinds of glass beads, plastic beads, corn cobs, and even walnut shells. Finally, a special plastic made it possible to expose the garnets from both sides efficiently. The Mineralogical and Geological Museum at Harvard University, the American Museum of Natural History, Yale University, the University of Arizona, and Bill Larson of Pala International all currently own these specimens.

Tao Hsu and Andrew Lucas
GIA, Carlsbad

Australian opal beads with blue play-of-color. The Australian Opal Shop (Gold Coast, Australia) had a variety of goods on display at Tucson's Globe-X Gem & Mineral Show. Owner John McDonald primarily deals in boulder opal with a sandstone matrix from the Winton mining area in Queensland. Untreated specimens can be polished to create beautiful slabs of boulder opal with or without matrix, though sandstone with microscopic bits of opal must be treated to make the play-of-color visible. The pieces are soaked in a fatty oil (usually vegetable oil) rather than petroleum-based oils, which leave a residue. The finished product ranges from multicolored to dark blue, depending on the size of the opal pockets and the spherical structure. What appears as dark blue bodycolor is actually blue play-of-color. The treated rough is usually fashioned into beads (figure 28).

Donna Beaton
GIA, New York

Honduran and Turkish opal. Harald Mühlinghaus (Opal Imperium, Enkirch, Germany) has been exhibiting at the Pueblo Gem & Mineral Show for more than 20 years. The company sources, fabricates, and sells a number of colored gemstones, but their main focus is opal from Australia, Mexico, Honduras, and other locales. At the booth were some unusual examples that have rarely been documented, such as a banded opal (figure 29, left) obtained about 30 years ago from an unrecorded Honduran location. This material occurs as solid vertical veins in matrix with approximately 1 cm stratifications of play-of-color, which indicate the cyclical concentration and the formation of the silica spheres that form opal. The phenomenon is most distinct in fairly sizable pieces of rough, with 1–3 mm opal layers

Figure 28. At the Globe-X show, these polished Australian opal beads (in sandstone matrix) displayed blue play-of-color. Photo by Donna Beaton.


Figure 29. Left: This Honduran banded opal, 10 cm in height, shows a 1–3 mm thick stratified opal layer attached to matrix. Right: Turkish dendritic opal was available as cabochons. Photos by Donna Beaton.

on matrix measuring 5–15 cm across, which makes these specimens more suitable for display than for jewelry. Some of the smaller examples displayed only nonphenomenal layers, while others had play-of-color fading to potch at each cycle.

Also on display were dendritic opal cabochons (figure 29, right) from rough obtained from Simav, Turkey, about four years ago. This material, which Mühlinghaus called "Turkish dendritic opal," has been cut so that each piece shows clearly delineated opaque white and semitransparent areas, embedded with fine branched black inclusions reminiscent of traditional Japanese *tategaki* characters.

Donna Beaton

African rhodochrosite and Colombian quartz with trapiche patterns. Also at the Pueblo show, Germán Salazar (Idar-Oberstein and Bogotá) and Gaetano Lacagnina (L.G. Gemme, Milan) shared a booth that featured an eclectic assortment of gems and minerals. Mr. Lacagnina, who also operates a lab and cutting factory, specializes in unusual and fine mineral specimens. Of particular note were high-quality rhodochrosites from the N'Chwaning mining area in the Northern Cape province of South Africa (figure 30, left). N'Chwaning, noted for having Africa's largest manganese reserves, also produces manganite, ettringite, and other Mn-bearing minerals. Noteworthy on Mr. Salazar's side of the booth were polished hexagonal quartz slices bearing a spoked trapiche-like pattern (figure 30, right). Coincidentally, the quartz was from the Boyacá region of Colombia, which regularly produces trapiche emerald. The patterned areas are found at the core of larger quartz crystals. Viewed in a polariscope, the growth directions and fibrous inclusions are very distinct. Although Mr. Salazar has marketed the slices as "trapiche quartz," he is considering branding this unique find as "Salazarite."

Donna Beaton

The fluid art of Angela Conty. Renowned lapidary, designer, and goldsmith Angela Conty created a jewelry collection exclusively for the 2016 Tucson gem and mineral shows. We had a chance to see some of her convertible pieces at the Hotel Tucson City Center.

Ms. Conty's artistic vision is heavily influenced by nature: Flowers, leaves, twigs, seed pods, and similar motifs


Figure 30. Left: A 6.0 cm tall rhodochrosite specimen from the N'Chwaning mining area in South Africa. Right: These domed hexagonal quartz slices from Colombia, measuring 3.5–4.5 cm across, exhibit inclusions reminiscent of trapiche emerald. The pattern becomes more distinct when viewed through cross-polarized filters. Photos by Donna Beaton.

Figure 31. This pin/pendant features two Oregon sunstones, a Chinese freshwater pearl, and diamond accents. Carved green chalcedony and a 1.50 ct zircon complete the design. The piece is set in 14K and 18K yellow gold. Photo by Robert Weldon/GIA; courtesy of Angela Conty.

Figure 32. This 18K yellow gold convertible pendant/pin features a 46.80 ct carved Oregon sunstone as its centerpiece. A chocolate Tahitian pearl drop and diamond accents help frame the carving. Photo by Robert Weldon/GIA; courtesy of Angela Conty.

are reflected in her work. The fluidity of her artistic expression strikes a perfect balance and flow between the gemstone carving and the jewelry design. Ms. Conty views her design and manufacturing process as the evolution of a work of art that often features a carved gemstone. Changes may occur when carving the stone, working the metal, or assembling the piece of art. When she has the rough in hand, she takes into consideration the stone's shape, its best orientation, and how it would look carved and set in jewelry. As the carving progresses, the rough might take an unexpected direction, even after the metalwork is finished. She feels that lapidary work and metalsmithing must blend and harmonize in order to create the perfect balance. This means the carving or the metalwork can be continually adjusted until the carving is ready to be set. In her words, "I gather together elements, cast and constructed, and begin to solder or weld until the carving, gemstones and metalwork begin to work together, always ready to make more changes. I add, move, and remove elements to create a better integration of carving and goldwork."

Her gemstone preferences include Australian opal, quartz, chalcedony, and her new favorite, Oregon sunstone. Her metal of choice is 18K gold, but she will sometimes use silver or 14K gold, depending on the design or the client's preference. The relationship between the stone and metal is beautifully demonstrated in the Oregon sunstone jewelry pieces shown in figures 31 and 32, which can be worn as either brooch or pendant.

Ms. Conty's combined talents in art and creative design took root more than 40 years ago at the State University of New York (SUNY) at New Paltz, where she earned undergraduate and graduate degrees in art. Her training included drawing, art history, painting, ceramics, sculpture, and silversmithing. She studied metalwork under Kurt Matzdorff, the founder of the Society of North American Goldsmiths (SNAG), and is a self-taught lapidary artist.

In 2002, Ms. Conty won second place in AGTA's Cutting Edge Awards in the Objects of Art category. Her work has been featured in numerous publications and books.

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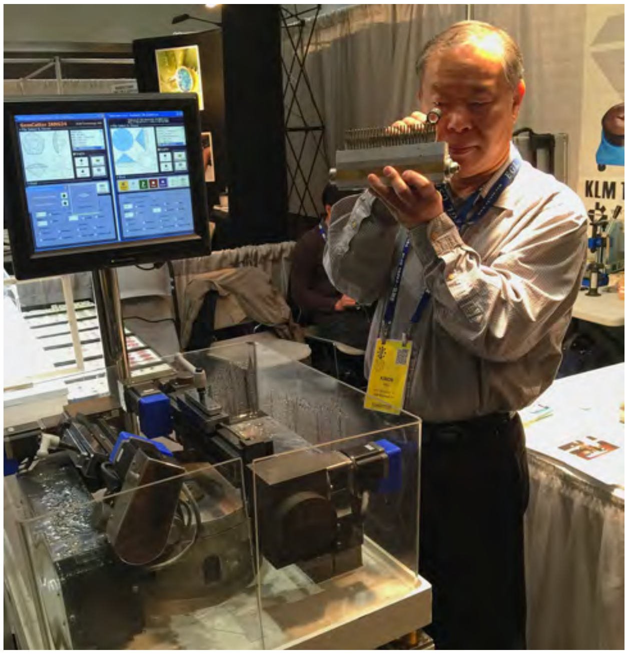

Figure 33. Kiwon Jang checks a cassette of stones during the Jang 1024's robotic cutting process. Photo by Tao Hsu.

Robotic colored stone cutting machines. At the technology pavilion of the AGTA show, master cutter Kiwon Jang of KLM Technology (New Brunswick, New Jersey) demonstrated the Jang 1024, a robotic system for cutting colored stones (figure 33).

Figure 34. A cassette of stones is cut using water as a cooling agent. Photo by Tao Hsu.

Figure 35. This cassette, which can hold up to 56 melee at one time, is shown holding 28 larger stones. Photo by Tao Hsu.

KLM provides cutting services to the gem trade. Mr. Jang began his career working with cubic zirconia in his native Korea. Since moving to the United States 30 years ago, he has developed multiple systems for automatic gem cutting, with 10 systems in KLM's New Jersey factory. The company also sells the machine to overseas clients and provides on-site training for the systems. *G&G* previously reported on one of his compact machines (Fall 2012 GNI, p. 233).

The Jang 1024 is his most recent product. The machine's process is controlled by a computer installed with designing and cutting software written by Mr. Jang. The water-cooled system (figure 34) is designed for mass production; depending on stone size, it can handle up to 56 melee at a time (figure 35). The machine can produce a round brilliant cut from 1 to 30 mm, while the largest size for emerald cuts is 25 mm. According to Mr. Jang, the maximum tolerance the machine can accommodate is 0.05 mm. The daily capacity of this machine is 2,000–4,000 melee between 1.0 and 3.0 mm, 400–800 stones between 3.5 and 10.0 mm, or 100–200 stones larger than 10.0 mm. Aside from periodically checking the stones, the entire process from preforming to polishing is done by the computer. Mr. Jang informed us that the majority of his clients are miners and cutting factories in Brazil and Russia, along with many African countries. Most of his customers in the United States are domestic dealers seeking fast local service.

Tao Hsu and Andrew Lucas

ERRATUM

In the Spring 2016 Lab Note on the largest blue HPHT synthetic diamond examined to date, the DiamondView images showing fluorescence and phosphorescence (p. 74) were listed in the wrong order.