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*Featuring:
Canadian
Diamonds*



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pg. 206

EDITORIAL

- 205 **The Liddicoat Legacy**
Alice S. Keller
- 206 **A Special Tribute to Richard T. Liddicoat**

FEATURE ARTICLE

- 208 **Diamonds in Canada**
B. A. Kjarsgaard and A. A. Levinson



This article chronicles the history of Canadian diamond exploration, with particular attention given to key discoveries in the 1990s. Also described are the production, sales, and marketing of these diamonds, as well as Canada's growing impact on the world diamond market.

NOTES AND NEW TECHNIQUES

- 240 **"Diffusion Ruby" Proves to be Synthetic Ruby Overgrowth on Natural Corundum**
Christopher P. Smith

A study describing the gemological characteristics that distinguish a new commercial product marketed as "Diffusion Ruby" from red lattice diffusion-treated corundum as well as from natural rubies.



pg. 235

REGULAR FEATURES

- 250 **Gem Trade Lab Notes**
- Bromellite • Charoite inclusions in a quartz-feldspar rock • Altered vs. natural inclusions in fancy-color diamonds • Diamond with "compact disc" inclusion • Hemimorphite • Sapphire, bulk or lattice diffusion treated • Bulk diffusion-treated sapphire with synthetic overgrowth • Synthetic sapphire treated by "traditional" bulk diffusion with transition elements • Sapphire with surface evidence of heat treatment
- 258 **Gem News International**
- Australia's Ellendale diamond mine opens • Aquamarine and spessartine from Tanzania • Brown beryl from Mozambique • Yellowish green and green chrysoberyl from Ilakaka, Madagascar • "Tashmarine": Diopside from central Asia • Carved emeralds from an archeological site in Colombia • Hemimorphite from Congo • Jeremejevite from the Erongo Mountains, Namibia • New morganite mine in Madagascar • Namibian gem localities • New opals from Brazil • Bicolored spessartine from Brazil • Pink/yellow spodumene from Afghanistan • Glass imitations encountered in Namibia • Plastic and steel pearl imitations • Gem cutting factories in Namibia • Conference reports • Announcements
- 276 **2002 Challenge Winners**
- 277 **Book Reviews**
- 280 **Gemological Abstracts**



pg. 254



pg. 270

The Liddicoat Legacy

The world of gemology lost a giant when GIA chairman and *G&G* editor-in-chief Richard T. Liddicoat passed away July 23, at the age of 84, after battling a lengthy illness. Widely respected as the “Father of Modern Gemology,” Mr. Liddicoat leaves behind thousands of admirers and an unparalleled level of achievement.

In the several weeks since Mr. Liddicoat’s passing, much has been written about his origins in Michigan, his hiring by GIA founder Robert M. Shipley in 1940, his unsurpassed contributions to gemological education and integrity as president of GIA, and his premier role in the development of GIA’s internationally recognized diamond grading system. In addition to his myriad accomplishments, any one of which would have left an indelible mark on the gem and jewelry industry, for more than 50 years—from 1952 until his death—this World War II Navy veteran stood at the helm of *Gems & Gemology*.

Over the decades, Mr. Liddicoat contributed dozens of groundbreaking feature articles, along with editorials, book reviews, and reports for the “Highlights at the Gem Trade Lab” column (which later became the Gem Trade Lab Notes section). In recent years, he preferred to stay behind the scenes, offering advice and direction. Although bedridden for the last few months of his life, he continued his involvement with the journal, evaluating articles, helping choose reviewers, and advising on editorial policy.

His most important contribution, though, was his unwavering support of the journal’s efforts to promote gemology as a scientific discipline. In the more than 22 years that I worked with Richard Liddicoat on *Gems & Gemology*, he was steadfast in his backing of the peer-review system and his promotion of new developments in technology and instrumentation, as increasingly sophisticated treatments and synthetics required new identification methods, and as continued prospecting brought more (and even new) gem materials from previously unknown sources. Ever the educator, he recognized the importance of quality information to the practicing gemologist in the 21st century.

I found both peace and pleasure in our conversations during the last few weeks of his life. He wanted to know all about the upcoming issues, delighted in the idea of *G&G*’s first fold-out chart (the Summer 2002 GIA Pink Diamond Color Chart), and was fervent in his desire to thank everyone connected with the special Spring 2002 “RTL” issue. But this very humble man was also concerned about his legacy. How would he be



remembered? What had he truly left behind in a life that spanned more than eight decades and a career that encompassed more than six of them? It was a privilege to remind him of the organization he had built, the many people he had guided, the dozens of awards he had received.

Yet I think he revealed his most meaningful bequest in a conversation we had a few days before he passed away. I had called to say hello, and he asked what I was doing. I told him I’d been editing the Gemological Abstracts section, which had to go into print the next day. “It’s not the most pleasant way to spend a beautiful Sunday afternoon, Mr. Liddicoat, but somebody has to do it, right?” I asked.

“Yes, Alice,” he replied very quietly. “Somebody has to do it right.”

That is the legacy Richard T. Liddicoat has left *G&G*, GIA, and the gem and jewelry industry: The standards, the resources, and the passion to do it right.

With Mr. Liddicoat’s passing, there also has been a passing of the torch at *Gems & Gemology*. At the request of *G&G* publisher (and GIA president) Bill Boyajian, I am honored to assume the title of editor-in-chief of *Gems & Gemology*. Brendan Laurs has been promoted to editor of the journal, and Stuart Overlin assumes the title of associate editor. All of us will be operating with the able assistance of our new managing editor, Thomas Overton. Also new on the masthead, Dr. James Shigley takes on the responsibilities of contributing editor in recognition of his very prolific two decades writing for *G&G*.

GIA received hundreds of condolences from around the world on the occasion of Mr. Liddicoat’s passing. We are pleased to share some of these with you on the next two pages. For more on the long, rich career of Richard T. Liddicoat, please see the article by Dona Dirlam and coauthors in the Spring 2002 issue of *Gems & Gemology*.

A handwritten signature in black ink that reads "Alice S. Keller". The signature is fluid and cursive.

Alice S. Keller, Editor-in-Chief
akeller@gia.edu

IN MEMORIAM



Richard T. Liddicoat

MARCH 2, 1918–JULY 23, 2002

This is about a gentle world-shaker. A man who, in his quiet way, changed the world of gems. A man who had a more beneficial effect on the gem industry than any other person. A man who had a multitude of trusting and admiring friends—and no enemies—all over the world. A man who was responsible for the education of hundreds of thousands of jewelry industry people. A man who changed the jewelry industry from a trade to a profession. A man who was revered by his staff and his students, past and present. A man who established world-wide acceptance of his standards of quality for diamonds and other precious stones where none existed before. A man who definitely proved that “nice guys can finish first.”

George Kaplan
Rye Brook, New York

Mr. Liddicoat made huge contributions toward the creation and development of gemology in Russia. We will always remember our Friend and Teacher.

Dr. Vladimir S. Balitsky
Institute of Experimental Mineralogy
Russian Academy of Sciences
Chernogolovka, Russia

It is rare that one has the privilege, as we had, to know a truly great person, whose actions and contributions change the lives of those around him for the better. Such was Mr. Liddicoat. As the “Father of Modern Gemology,” his innovations in gemological and business education, his leadership of GIA in various capacities for 60-plus years, and the example he set as an ethical, professional gemologist, educator, author, administrator, and researcher have altered and uplifted the world’s jewelry and gem industries and changed for the better the lives of their customers. . . .

The legacy of this humble scholar and great gemologist will continue to influence and affect gemological education and research throughout the world for uncountable generations to come.

William George Shuster
Senior Editor
Jewelers’ Circular Keystone
Halboro, Pennsylvania





We at the DTC are deeply saddened to hear the news that Richard Liddicoat passed away. . . . He was truly an outstanding individual and made an enormous contribution both to the GIA and also the diamond and jewelry industry. His vision and integrity were valued by generations of diamond people, particularly at the DTC and amongst our clients.

*Gary M. Ralfe
Diamond Trading Company
London, England*

I had known Richard as a friend for over fifty years. In my early days in gemology, Basil Anderson and Robert Webster were my English colleagues and even mentors, and I am pleased to say that I felt that Dick Liddicoat played similar roles from your side of the Atlantic.

*Alan Jobbins
Surrey, England*



We can't thank him too much for all that we in the diamond trade owe him. We have affection, admiration, and respect for him, for his remarkable personality, sincere academic and professional attitude to gemology, and his profound knowledge of the field.

*Hidetaka Kato and Hisao Kato
Kashikey Co., Ltd.
Tokyo, Japan*

Those of us in the diamond industry are eternally grateful for his work on the methodology of evaluating diamonds that led to today's standard. Indeed, he will be remembered for his impact on so many aspects of the business, in particular his influence on bringing integrity and superior ethics to the gem and jewelry industry.

*Vartkess Knadjian
Backes & Strauss
Antwerp, Belgium*



Mr. Liddicoat's lifelong devotion to gemology made him an unattainable example for all in our diamond community. His enormous contributions to development of the diamond industry will immortalize his name for coming generations.

*Yuri Rebrik
Director General
Kristall
Smolensk, Russia*



In a most unselfish manner, his love for gemstones attracted and conquered thousands of people around the world, and his works will fortunately produce new admirers and new leaders in this magnificent profession he cherished so much in his lifetime.

*Jules Sauer and Daniel Sauer
and the staff of Amsterdam Sauer
Rio de Janeiro, Brazil*

DIAMONDS IN CANADA

By B. A. Kjarsgaard and A. A. Levinson

A newcomer (since 1998) as a supplier of rough diamonds to the world market, Canada is currently the seventh most important diamond producer by weight and fifth by value. This article chronicles the history of the exploration for, and discovery of, primary diamond deposits throughout Canada (538 kimberlites are currently reported), with particular emphasis on the important kimberlite pipes in the Northwest Territories. Typically, these pipes are small but have high diamond grades. Sales of the rough diamonds, and the fledgling cutting and polishing industry in Canada, are described, along with branding initiatives and the marketing strategies of the producers. Canada will become an increasingly significant supplier of rough diamonds as prolific new mines start production, and this will have a growing impact on the world diamond industry.

For the first 60 years of the 20th century, the vast majority of diamonds came from kimberlite pipes and alluvial deposits in just a few countries in southern and western Africa, with minor contributions of alluvial diamonds from elsewhere, mainly South America (Janse, 1995a, 1996). This changed when diamonds were found in kimberlite or lamproite occurrences on other continents and elsewhere in Africa. The most important of these new discoveries resulted in major new production in Russia (then the Soviet Union) in the 1960s, Botswana in the 1970s, and Australia in the 1980s (Levinson et al., 1992). Since the 1990s, the spotlight has been on Canada, and Canadian diamonds promise to play an ever-greater role in the world market (figure 1).

This article provides a synopsis of the history of Canadian diamond exploration in the first 60 years of the 20th century, followed by a comprehensive review of diamond exploration and discoveries in Canada since the 1960s. Special attention is given to the key events and discoveries in the 1990s, starting with the Lac de Gras area in the Northwest Territories (NWT), followed by Alberta, Saskatchewan, Ontario, and, finally, Quebec. Nothing has yet matched the excitement of the opening of Canada's first diamond mine, the Ekati Diamond Mine™, in 1998, but a number of other projects are either at the

construction stage (the Diavik project) or in advanced stages of evaluation or development (Snap Lake, Gahcho Kué, Jericho, and Victor). We will also examine diamondiferous kimberlites, such as those in Saskatchewan and Alberta, that have significant potential. In total, approximately 538 kimberlites are now known throughout Canada (figure 2; predominantly in the NWT), over 50% of which contain diamonds. Ninety percent of these have been found in the last decade.

The unusual characteristics of the Lac de Gras kimberlites (such as their small size but high diamond grades) are compared with those of producing kimberlites worldwide. The current and anticipated contributions of rough diamonds from Canada's mines to the world supply are discussed, as are the manufacturing and marketing (including branding) of Canadian diamonds. Note that a glossary is provided on page 212; terms defined therein are shown in italics the first time they appear in the text.

This review is based on, and limited by, the information available from recognized sources, mainly the open literature, including public statements from

See end of article for About the Authors and Acknowledgments.
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Figure 1. The first Canadian diamonds to enter the world market came from the Ekati Diamond Mine™, which opened in 1998 after decades of exploration by various companies and individuals. Each of the Ekati diamonds in the rings weighs approximately 1 ct, and the loose Ekati diamond weighs 1.29 ct; the diamonds in the earrings are each 0.10 ct. Courtesy of BHP Billiton Diamonds Inc.; photo © GIA and Harold & Erica Van Pelt.



exploration groups. However, much information is unpublished, veiled in the secrecy of mining company files. For example, De Beers¹ divulged in 1999 that since it started exploring in Canada in the early 1960s, it had discovered more than 170 kimberlites (some with joint-venture partners) in 11 different regions (Beardmore-Gray, 1999); no information has been made public on most of these kimberlites or the specific regions. While it is impossible to estimate what other information has not been revealed, we believe that we have omitted no major discoveries.

BACKGROUND

The possibility of diamonds occurring in Canada was raised over a century ago by Professor W. H. Hobbs (1899), who was the first person to make a convincing argument that diamonds in the Great Lakes states were transported by glaciers from a specific region in Canada (the James Bay Lowland; figure 3). Isolated discoveries of diamonds were reported in the eastern U.S. (e.g., North Carolina) as early as the 1840s, but diamonds found in the Great Lakes states from 1876 onward are the only ones of

significance from a Canadian perspective. Nevertheless, serious diamond exploration did not begin until the 1960s, and major kimberlite discoveries were not made until the 1980s. Why did it take so long to discover kimberlite *pipes* in Canada if they are actually relatively abundant? The answer is twofold: logistical and glacial.

Logistical factors include the remoteness and inaccessibility of some of the most favorable geologic areas (e.g., *Archean cratonic* rocks in the NWT, Nunavut, northern Ontario, and Quebec; again, see figure 2). Further, large portions of these areas consist of small, shallow lakes on which floatplanes cannot land as they routinely do in other parts of Canada. Finally, the climate limits the field season for regional exploration to only five months (May–September) or less. These factors have made exploration in much of Canada challenging and expensive. Diamond exploration was also hampered by the effects of glaciation (e.g., the deposition of *glacial drift*) until *indicator mineral* transport in glacial materials was understood. Essential aspects of glaciation, as they apply to diamond exploration in Canada, are presented in box A.

1900–1959: SIX DECADES OF CONTEMPLATION AND INACTIVITY

In the 60 years following the publication of the Hobbs (1899) article, many additional diamond discoveries in glacial drift were reported in the Great Lakes states (e.g., Blatchley, 1903; Hausel, 1995),

¹ The Canadian exploration arm of De Beers Consolidated Mines Ltd. has operated, since 1960, under a variety of corporate names: Hard Metals Canada Ltd., Canadian Rock Co. Ltd., Diapros Canada Ltd., Monopros Ltd., and most recently De Beers Canada Exploration Inc. Similarly, Rio Tinto plc. and their wholly owned subsidiaries have explored for diamonds in Canada under different names, including Kennecott Canada Ltd., over the years.



Figure 2. Canadian kimberlites, and other rocks that are sometimes associated with diamonds, are shown here with the major geological terranes. Diamonds have been confirmed at all the kimberlite localities except nos. 20 and 22. Various intermediate to ultrabasic (nonkimberlitic) rocks mentioned in the text are also shown; all except nos. 33 and 34 contain diamonds. Localities: (1) North Baffin Island; (2) Brodeur Peninsula; (3) Somerset Island; (4) Victoria Island; (5) Darnley Bay; (6) Kikerk Lake (Coronation Gulf); (7) Contwoyto Lake; (8) Ranch Lake; (9) Lac de Gras; (10) Snare Lakes; (11) Carp Lake; (12) Snap Lake; (13) Gahcho Kué (Kennady Lake); (14) Dry Bones Bay; (15) Birch Mountains; (16) Buffalo Hills; (17) Mountain Lake ultrabasic pipes; (18) Cross; (19) Fort à la Corne; (20) Snow Lake–Wekusko; (21) Akluilâk minette dike; (22) Rankin Inlet; (23) Kyle Lake; (24) Attawapiskat; (25) Wawa ultrabasic dikes and volcanic rocks; (26) Kirkland Lake; (27) Lake Timiskaming; (28) Ile Bizard alnöite; (29) “Indicator lake”; (30) Otish Mountains; (31) Wemindji; (32) Torngat Mountains aillikite dikes; (33) Saglek aillikite dikes; (34) Aillik Bay aillikite dikes; (35) Mountain diatreme alkali basalt. All these localities are mentioned in the text except for nos. 1, 2, 5, 20, and 22 (which are listed in table 3), and nos. 21, 33, and 34 (which are of minor importance and are not mentioned in the text or tables). Specific localities are cited in the text as, e.g., “figure 2 [26],” with the locality number in brackets.

mostly in Indiana and Illinois, for a total of 81 by 1967 (Gunn, 1968). During this time, however, little was written about diamonds or their primary sources in Canada. For this period (1900–1959), we found only 11 publications (excluding a few newspaper and other unsubstantiated reports) that bear directly on the subject: seven articles (Blue, 1900; Blatchley, 1903; Bell, 1906; Satterly, 1949; Field, 1949 and 1950, which are essentially identical and considered one source; Meen, 1950; and Douglas and MacGregor, 1952), two abstracts (Farrington, 1908; Kunz, 1931), and two minor entries of about 65 words each (Kunz, 1906, 1913). At the same time,

diamond exploration activities in Canada also were limited (table 1).

Blue (1900) suggested that the diamonds might originate from carbonaceous slates in northern Ontario (e.g., in the Sudbury area). Blatchley (1903) and Kunz (1931) were favorably inclined toward two Canadian sources for the Great Lakes diamonds: the James Bay area and the north shore of Lake Superior (figure 3). Bell (1906) favored multiple sources in the Lake Superior–Lake Huron region, but rejected the James Bay Lowland because of the great distance from the diamond occurrences. Farrington (1908) proposed, without specifics, the general region of



Figure 3. Early evidence of possible diamond-bearing kimberlites in Canada was provided by the discovery of isolated diamonds in glacial deposits in the Great Lakes states of the U.S. This map shows the limit of Pleistocene glaciation and the last glacial advance, the number of known diamond occurrences in each state (in parentheses), and the paths that the diamonds may have taken from their presumed source(s) in the James Bay Lowland. Also indicated is the location of the first authenticated diamond found (in 1971) in glacial deposits in eastern Canada (near Timmins): the 0.255 ct Jarvi diamond. The kimberlites at Lake Ellen, Michigan, have been suggested, but never confirmed, as a possible source of the diamonds in the Great Lakes states. After Hobbs (1899), Brummer (1978, 1984), and Levinson et al. (1992).

Lake Superior as the only source. Although Satterly (1949) never mentioned the word *diamond*, he included the first reported occurrence of kimberlite in Canada: two thin *dikes* (the largest 6 inches [15 cm] wide) that were intersected during drilling for gold in Michaud Township, near Kirkland Lake, Ontario, in 1946 (figure 2 [26]).

Field (1949, 1950) reviewed publications of the previous half-century and was enthusiastic about the possibility of diamonds occurring in Canada but offered no new insights. Meen (1950) observed that all the major diamond-bearing kimberlites known at that time (i.e., those in South Africa) were associated with rocks of Precambrian age. As much of Canada is underlain by rocks of similar ancient age, he recommended exploration for diamonds in those areas. Nevertheless, in the 1950s most Canadian mining companies and academics believed that economic diamond deposits could be found only in southern Africa (e.g., Duval et al., 1996).

There are brief reports of diamonds being sought, unsuccessfully, by survey parties during construction of the Transcontinental Railroad, immediately north of the Great Lakes (Kunz, 1906), in northern Quebec near Matagami Lake (Kunz, 1913), and in what turned out to be a meteorite crater in the Ungava region of northern Quebec (Meen, 1950). Also during these first 60+ years, diamonds were periodically reported from various parts of Canada. However, all were misidentifications, unsubstantiated because of poor documentation, or of doubtful authenticity (including probable fraud). These reported discoveries are not considered further in this article, but are listed in the *Gems & Gemology* Data Depository (<http://www.gia.edu/gandg/ggDataDepository.cfm>).

Douglas and MacGregor (1952) recounted, in detail, an unsuccessful attempt in 1910 by five prospectors to find diamonds in the Nottaway River area, Quebec, near James Bay. To the best of our knowledge, this is the only recorded, apparently creditable, attempt before 1960 at field exploration specifically for diamonds.

By the mid-1950s, however, the foundation was being laid for systematic diamond exploration programs in the succeeding decades as a few academics—as well as geologists and engineers employed by mining companies—expressed interest in Canada's diamond potential. Notably, in 1956 P. V. Freeman (then a Ph.D. candidate at McGill University) suggested that sampling *eskers* [see box A] would yield results similar to those

GLOSSARY

aeromagnetic survey An airborne geophysical survey using a towed sensor that can detect magnetic anomalies; these anomalies may indicate the presence of kimberlite.

Archean The earlier (i.e., prior to 2.5 billion years ago) of two great divisions of Precambrian time; the earliest eon of geologic time.

cratons Large, ancient, stable portions of the earth's crust (continental nuclei) in which all commercial diamond-bearing kimberlites have been found.

diatreme A pipe (conduit) filled with angular volcanic fragments that was formed by a gaseous explosion. Many of the diamond-bearing kimberlites at the type locality in Kimberley, South Africa, are diatremes.

dike A tabular igneous intrusion that cuts across the structure or bedding of pre-existing rock. On rare occasions (as at Snap Lake, NWT), economic kimberlites will occur as dikes.

esker A long, narrow, sinuous ridge composed of glacial drift (typically sand and gravel) deposited by subglacial streams.

exploration grade The grade (ct/tonne) of a deposit estimated from a relatively small bulk sample and subject to revision with additional sampling before mining is initiated.

exploration stone value The value of rough diamonds (US\$/ct) from a deposit estimated from <5,000 carats of diamonds and subject to revision with additional sampling before mining is initiated.

glacial drift A general term for all material transported and deposited by or from a glacier or by running water emanating from a glacier.

glacial till Unsorted rock materials (e.g., clay, sand, gravel) transported and deposited by a glacier, without reworking by meltwater.

indicator minerals Minerals geologically associated with diamonds (e.g., Cr-rich pyrope garnet, Cr-spinel), but significantly more abundant, which can be used as proxies to locate a primary source of diamonds.

mafic An igneous rock composed chiefly of one or more iron- and magnesium-based minerals; such rocks are generally dark colored. On rare occasions (as at Wawa, Ontario), mafic rocks will contain diamonds but so far they have not been economic.

microdiamond A rough diamond that is <0.5 mm (in some definitions <1.0 mm) in diameter; usage of this term varies, and in some cases the diameter applies to only one dimension whereas in others it applies to all dimensions.

modeled grade The grade (ct/tonne) of a deposit estimated from a relatively small sample based on statistical methods using micro- and macro-diamond size counts (see, e.g., Rombouts, 1999).

modeled stone value The value of rough diamonds (US\$/ct) from a deposit estimated from a relatively small sample, based on statistical methods using values from micro- and macro-diamond counts (see, e.g., Rombouts, 1999).

pipe Cylindrical or carrot-shaped structure that is filled with any one of several types of kimberlite (e.g., hypabyssal, diatreme, resedimented).

ramp-up The time and/or process required to bring mine production to full capacity.

sill A tabular igneous intrusion that parallels the bedding or foliation of the host rock.

ultrabasic An igneous rock, such as kimberlite or lamproite, having a very low silica (<45% SiO₂) content.

obtained from stream sediments, which are very effective for mineral exploration in nonglaciated areas (Brummer et al., 1992a). A few years later, in 1960, De Beers signaled its interest in Canada when it rehired Canadian geologist Dr. Mousseau Tremblay, who had left the company only the year before to return to Canada (Duval et al., 1996). Dr. Tremblay had several years of diamond exploration experience in East Africa, including the area around

the Williamson (Mwadui) mine in Tanganyika (now Tanzania).

1960–1969: SERIOUS DIAMOND EXPLORATION BEGINS

This decade ushered in the modern era of diamond exploration in Canada, with the sudden appearance of several diamond exploration programs by two

companies in particular: Selco Exploration Co. (the Canadian subsidiary of Selection Trust, a British company) and De Beers (South Africa). Both companies were experienced diamond explorers internationally, but were new to North America. In addition, studies related to diamond exploration were undertaken by various federal and provincial geological surveys. These early projects attempted to evaluate large areas, with spotty results, as described below.

Northeastern Ontario: James Bay Lowland. Initial efforts to find diamonds in Canada were concentrated in the James Bay Lowland of northern Ontario, an area that is extremely difficult to explore because of the abundant bogs, uninterrupted glacial cover, and poor drainage (figure 4). Selco and De Beers found kimberlite indicator minerals (including pyrope garnet) at 20 locations over a large area (~10,000 km²), but no kimberlite or diamonds (Brummer, 1978). Work by the Ontario Department of Mines in 1966 (Brown et al., 1967) also confirmed the presence of indicator minerals (Kong et al., 1999). The activities of all three groups supported the suggestion of Hobbs (1899) that the James Bay Lowland might be the source of the Great Lakes diamonds.

Northeastern Ontario: Kirkland Lake–Lake Timiskaming. In the early 1960s, De Beers followed a trail of indicator minerals in an esker (and *glacial till*) to the Guigues pipe (Lake Timiskaming area; figure 2 [27]) in Quebec. This was the first kimberlite pipe found as a result of geologic exploration rather than by accident. However, the absence of diamonds in a multi-tonne sample of glacial material immediately “down-ice” of the kimberlite precluded drilling or sampling the kimberlite itself (M. Tremblay, pers. comm., 1998). Early exploration in the Kirkland Lake–Lake Timiskaming area of Ontario (and adjacent parts of Quebec) was at least in part due to the 1946 discovery of thin kimberlite dikes in a gold mine near Kirkland Lake (Satterly, 1949). In addition, government-funded studies in this area in the early to mid-1960s demonstrated the validity of esker sampling for kimberlite indicator minerals (Lee, 1965; Lee and Lawrence, 1968).

Ile Bizard, Quebec. Attention soon shifted to Ile Bizard, an island in the St. Lawrence River, 14 km west of Montreal (figure 2 [28]). Several intrusions there were first described by Harvie (1910) as alnöites (a rare rock macroscopically similar to kimberlite, but not known to contain economic diamond deposits).

TABLE 1. Milestones in the history of diamond discoveries in Canada.

Year	Milestone	Reference
1899	First documented suggestion that diamonds occur in Canada	Hobbs (1899)
1946	First Canadian kimberlites (two thin dikes) found near Kirkland Lake, Ontario	Satterly (1949)
1956	The use of eskers as a sampling medium in glacial terrain first suggested by P. V. Freeman	Brummer et al. (1992a)
1957	Information on using indicator minerals for regional diamond exploration (pioneered in Russia) first available in English	Davidson (1957)
1960	De Beers signals interest in diamond exploration in Canada with the recruitment of geologist Dr. Mousseau Tremblay	Duval et al. (1996)
1960	First modern diamond exploration project in Canada (by Selco) begins in the James Bay Lowland	Brummer (1978)
1961	First regional heavy mineral survey across Canada initiated by De Beers	Brummer (1978)
Early 1960s	First kimberlite pipe (Guigues in Quebec) discovered by geological exploration, rather than by accident, in the Lake Timiskaming area	M. Tremblay (pers. comm., 1998)
1964	The Munro esker (Kirkland Lake, Ontario) study is the first to publicly demonstrate the value of eskers in diamond exploration in Canada	Lee (1965); Lee and Lawrence (1968)
1968	First diamonds (10 minute) recovered from a primary source in Canada, at Ile Bizard, Quebec	Brummer (1978, 1984)
1971	The Jarvi diamond (0.255 ct, found near Timmins, Ontario) is the first authenticated diamond to be discovered in glacial drift in Canada	Brummer (1978, 1984)
1973	The first kimberlite field in Canada, the Somerset Island field, is recognized	Mitchell and Fritz (1973)
1976	Exploration begins in the Cordillera; the Cross diatreme in British Columbia is recognized as kimberlite	Pell (1987)
1979	Otish Mountains (“Indicator lake”) kimberlite discovered in Quebec	Gehrisch et al. (1979)
1981–1982	Charles E. Fipke and Stewart L. Blusson explore the Mountain diatreme and Blackwater Lake areas of NWT	Fipke et al. (1995b); Krajick (2001)
1981–1984	Numerous kimberlites discovered by De Beers in the Kirkland Lake area (Ontario), establishing the Kirkland Lake kimberlite field	Sage (1996)
1983	Fipke incorporates Dia Met Minerals to explore for diamonds	See text
1987	First kimberlite found in Saskatchewan, at Sturgeon Lake; discovery of the Fort à la Corne kimberlite field announced in 1989	Lehnert-Thiel et al. (1992)
1988	The Attawapiskat kimberlite field (James Bay Lowland, Ontario) discovered by De Beers	Kong et al. (1999)
1989	Fipke and Blusson arrive in Lac de Gras (NWT) and begin to stake claims	Fipke et al. (1995b); Krajick (2001); see text
1991	Diamond-bearing kimberlite discovered at “Point lake” in the Lac de Gras area	See text
1997	First kimberlite discovered in Alberta, in the Buffalo Hills	J. A. Carlson et al. (1999)
1998	The Ekati Diamond Mine in NWT officially opens with mining of the Panda kimberlite	See text
1999	Government approval received to start construction of the Diavik mine; diamond production scheduled to begin in early 2003	See text

BOX A. GLACIATION AND DIAMOND INDICATOR MINERALS

Glaciation. During the Pleistocene epoch (1.6 million to 10,000 years ago), the time of the Ice Age, glaciers periodically covered up to 95% of Canada. As the glaciers advanced, they eroded the earth's surface, often transporting and scattering the abraded material (including the occasional diamond) many hundreds of kilometers from its source. Eventually, this material was deposited as glacial drift. Glacial drift in Canada may reach more than 300 m (~1,000 feet) in thickness over buried valleys, but usually it is much shallower and in some places it is absent.

Kimberlite is generally softer than granite and other igneous and metamorphic rocks that are typical of the Precambrian Shield areas into which it is emplaced. Therefore it may be preferentially eroded,



Figure A-1. The sinuous ridge shown here is an esker at Exeter Lake, NWT, located about 20 km northwest of the Ekati mine. This photo (looking east) was taken in 1955 in conjunction with a geological investigation of its heavy mineral content (Folinsbee, 1955), near the location that was sampled three decades later by C. E. Fipke. This esker can be traced for ~515 km (~320 miles); at this location, it is up to 24 m (~80 feet) above lake level and 150 m wide in places. Photo courtesy of the Geological Survey of Canada; supplied by R. E. Folinsbee.

De Beers acquired an option on the property in 1967. In 1968, the Pain de Sucre ("Sugar Loaf") occurrence yielded 10 minute diamonds weighing a total of 0.0605 ct (the largest, 0.0244 ct [2.44 points]), from a 29 cubic yard [22 m³] sample, which showed that the intrusions had no commercial potential. Nevertheless, these are the first authenticated diamonds recovered from a primary source of any type in Canada (for details of these occurrences, see Brummer, 1978, 1984; Raeside and Helmstaedt, 1982; and Mitchell, 1983).

sometimes deeply, by glaciers. Today, the resulting depressions are often occupied by lakes and swamps. This explains why numerous kimberlites are under lakes in certain parts of Canada, a possibility first mentioned by Meen (1950) and confirmed by the major kimberlite discoveries in the Lac de Gras area starting in 1991. Since kimberlites are not typically seen on the surface in Canada, diamond prospecting is based on the premise that indicator minerals and kimberlite boulders in glacial drift can be traced back to their primary source (see, e.g., McClenaghan et al., 2001).

Eskers are particularly important for prospecting in a glaciated area. These long (up to 500 km if gaps are included), narrow, sinuous ridges are composed of glacial drift that was deposited from subglacial streams (figure A-1). Geologists have traced diamond indicator minerals for great distances in eskers to locate numerous kimberlites (initially in Ontario, but later in the NWT).

Diamond Indicator Minerals. Diamonds are extremely rare, even in economic deposits (usually <1 ct/tonne of kimberlite). However, certain other minerals geologically associated with diamonds (e.g., Cr-rich pyrope garnet, Cr-spinel) are usually far more abundant (figure A-2). These diamond indicator minerals can therefore be used to locate the primary source of diamonds (figure A-3). The concept was initially used in the 1870s in South Africa on a local scale when the association of pyrope with diamond was first recognized (see Janse, 1996, for a summary of this topic). The great diamond discoveries in Yakutia (Russia) in the 1950s were achieved by large-scale sampling of stream sediments for indicator minerals (mainly pyrope; Davidson, 1957; Smith, 1960). In 1956, P. V. Freeman was the first on record to suggest that eskers could be used for sampling in diamond exploration. In Canada, glacial till, eskers, and stream sediments are sampled for indicator minerals.

Central and Western Canada. Starting in 1961, De Beers undertook systematic indicator mineral sampling of glacial materials and stream sediments from the foothills of the Rocky Mountains (in Alberta) east to the Appalachian region (in Quebec) and from the U.S. border north to 54° latitude (Brummer, 1978; M. Tremblay, pers. comm., 1998). Lehnert-Thiel et al. (1992) indicate that De Beers found diamond indicator minerals in southeast Saskatchewan in 1963. There is no further published information on the results of this project.

Many of the indicator minerals occur in various rock types in addition to kimberlite, so the recognition of those associated with diamonds requires training and experience. Initially, they were recognized by the characteristic colors (e.g., deep red or purplish red for pyrope, and “emerald” green for chrome diopside) of the grains. Later, in the 1950s and ‘60s, careful measurements of physical (e.g., R.I. and S.G.) or crystallographic (unit cell dimensions) properties became diagnostic. Starting in the early 1970s, the electron microprobe became the instrument of choice for analyzing the chemical composition of the small grains (see, e.g., Gurney and Switzer, 1973).

Today, there are classification schemes for all the important indicator minerals, based on their chemistry, that are capable of empirically predicting whether or not a specific grain could have originated from a diamondiferous kimberlite. The methods of



Figure A-2. Several indicator minerals are used to explore for kimberlites in Canada. These include, from top to bottom: Cr-pyrope garnet, eclogitic garnet, Cr-spinel, olivine, picroilmenite, Ti-pyrope garnet, and Cr-diopside. Photo by Penny R. Maki-Scott, Saskatchewan Research Council.

diamond indicator mineral sample collection, analysis, and interpretation have become widely disseminated (see, e.g., Fipke et al., 1995a; McClenaghan and Kjarsgaard, 2001), although the finer points of interpretation are proprietary.

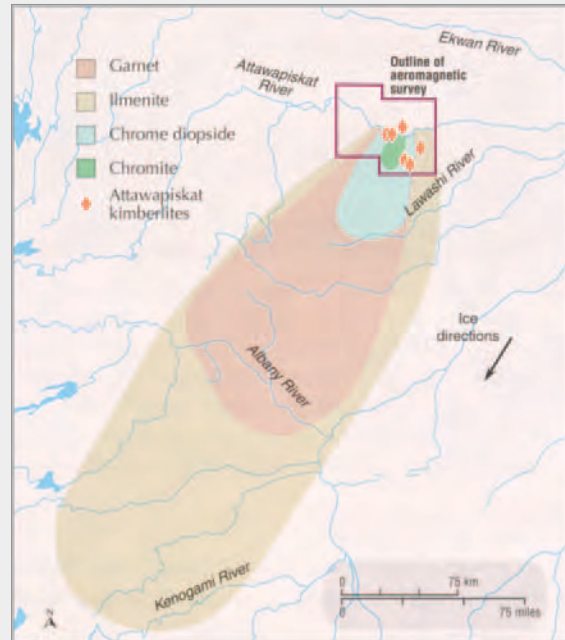


Figure A-3. In 1984–87, De Beers used indicator mineral sampling (assisted by airborne geophysical surveys) in the James Bay Lowland of northern Ontario to locate diamondiferous kimberlites in the Attawapiskat River area. The indicator-mineral dispersion patterns for chromite, chrome diopside, pyrope garnet, and ilmenite are shown here. Dispersion of the ilmenite grains is detectable more than 300 km from the kimberlite source, whereas chromite and chrome diopside yield much smaller dispersion halos closer to the source because they are more easily weathered. The indicator minerals were collected from streams that were eroding glacial deposits (after Kong et al., 1999).

1970–1979: FEW AND DISAPPOINTING DISCOVERIES

As the 1970s unfolded, exploration activity began to shift away from Ontario, mainly to the north and west. At the same time, interest from academics increased with, for example, the detailed study of kimberlites on Somerset Island in the Arctic archipelago (e.g., Mitchell and Fritz, 1973). Nevertheless, activities during this decade would eventually lead to the discovery and operation of

Canada’s first diamond mine, in the Northwest Territories.

The Jarvi Diamond (Eastern Ontario). In late 1971, a 0.255 ct diamond was found by Reno Jarvi while sampling an esker near Timmins, Ontario (Brummer, 1978, 1984; again, see figure 3). Its primary source has never been located, but this was the first authenticated diamond to be found in glacial drift in Canada—almost a century after the 1876 discovery of the first

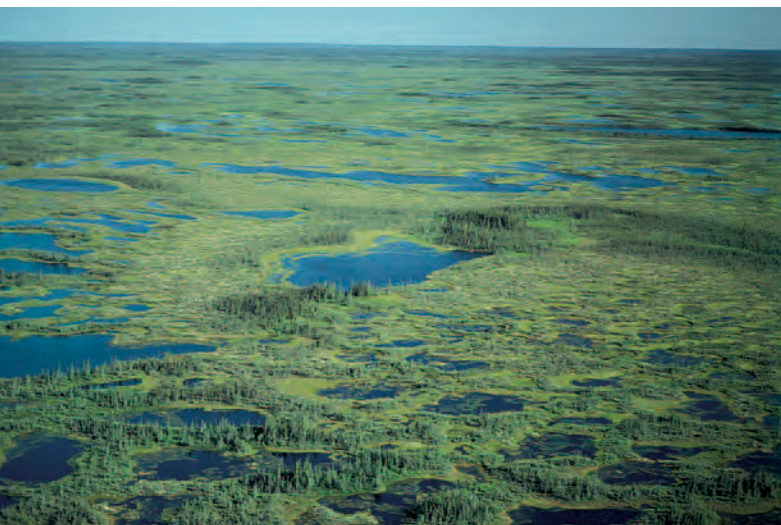


Figure 4. The James Bay Lowland is characterized by flat topography (the result of deposition of glacial drift), abundant bogs, uninterrupted glacial cover, and poor drainage. Such conditions make exploration problematic because of difficult access and limited sampling media. This photo was taken near the Attawapiskat kimberlite field in July 1984 by L. H. Thorleifson.

diamond found in glacial material in the Great Lakes states (Hobbs, 1899). Recovery of the Jarvi diamond on the “down-ice” path taken by glaciers from the James Bay Lowland helped maintain interest in northeastern Ontario. It also gave further importance to sampling eskers.

Northeastern Ontario: James Bay Lowland. The Ontario government encouraged diamond exploration in this region by conducting extensive reconnaissance surveys, which revealed various areas with unusual concentrations of diamond indicator minerals. These areas overlapped those explored by industry in the 1960s (Wolfe et al., 1975; Brummer, 1978).

Northeastern Ontario: Kirkland Lake. In 1978, the innovative Kirkland Lake Initiatives Program (KLIP) started. The Ontario government supported this four-year project to stimulate exploration and mining for gold, base metals, and diamonds (summarized by Brummer et al., 1992a; Sage, 1993). Maps were published of areas with anomalous concentrations of diamond indicator minerals and geophysical (e.g., aeromagnetic) anomalies, starting in 1979. These data helped stimulate the mining companies to renew exploration for diamonds in the early 1980s.

Somerset Island. Originally described in the early 1960s as “ultrabasic igneous breccias” (Blackadar

and Christie, 1963), rocks on Somerset Island (figure 2 [3]) were later identified as kimberlites by Mitchell and Fritz (1973); this is the first kimberlite field² discovered in Canada. Because there is no forest or glacial drift cover in this area, the kimberlites are relatively easy to recognize by the contrast of their dark color against the pale-hued carbonate host rocks (figure 5). Although 19 kimberlites were located (Brummer, 1978), bulk sampling of the main Batty pipe yielded only five small diamonds and indicated an uneconomic grade of 0.01 ct per tonne (Kjarsgaard, 1996).

Quebec. In 1979, Uranerz Exploration and Mining Ltd. drill tested an aeromagnetic anomaly at “Indicator lake,” Otish Mountains, in central Quebec (figure 2 [29]) during a uranium exploration program. Drill holes penetrated a kimberlite (Gehrisch et al., 1979), the first in Quebec, but beyond this little is known.

Cordillera Region (Eastern British Columbia and Western NWT). Exploration for diamonds in the Cordillera began in 1976 when a Cominco Ltd. field party recognized that an igneous breccia first noted by Hovdebo (1957) was a kimberlite. It is now known as the Cross *diatreme* (figure 2 [18]). This initiated an exploration rush from 1977 to 1980 that was funded, in part, by two major companies new to diamond exploration in Canada: Superior Oil Co. and Falconbridge Nickel Ltd. Within a few years, these and other companies had discovered many intrusions with broadly kimberlitic affinities (~40 in southeastern British Columbia alone) in five clusters,² stretching ~2,000 km (~1,200 miles) in a north-northwest direction to the Mountain diatreme (figure 2 [35]; figure 6) in the Mackenzie Mountains, NWT (Ijewliw and Pell, 1996). *Microdiamonds* (<0.5 mm) have been reported in several of the Cordillera intrusions (Godwin and Price, 1986; Ijewliw and Pell, 1996), but to date none of the intrusions has proved economic. Nevertheless, the Cross diatreme was the only true kimberlite (Pell, 1987; Hall et al., 1989; Fipke et al., 1995a, table 4) found in the Canadian Cordillera until the early 1990s. Notably,

² Kimberlite typically occurs as small (almost always <1,000 m diameter; ~80 ha) bodies of variable shape, that are usually grouped together in small clusters. A number of clusters within an area constitute a kimberlite field. Several fields comprise a kimberlite province (e.g., the Slave province). Kimberlites in clusters and fields are all about the same age, but this is not always the case for kimberlites in provinces.

however, the Mountain diatreme alkali basalt was a significant factor in the sequence of events that led to the discovery of the Lac de Gras kimberlite field.

1980–1989: PERSEVERANCE BEGINS TO PAY OFF

The 1980s opened with the most prominent exploration in Ontario, and with clear signs that diamond exploration was spreading throughout the country. Furthermore, mining companies recognized that a major problem had hindered their Canadian activities to date: Diamond experts with experience from other countries (e.g., in southern Africa, Australia) did not necessarily have a strong background in glacial geology. As a result, some had undertaken sampling programs in Canada without knowing the nature of the glacial materials being sampled (e.g., eskers, till). This resulted in a limited understanding of how far the glacial materials had been transported. In the 1980s, improved airborne geophysical surveys and the geological knowledge of glacial deposits, combined with sampling for diamond indicator minerals, led to many significant discoveries (again, see table 1).

Northeastern Ontario: James Bay Lowland. From 1979 to 1982, Selco, joined by Esso Minerals Canada in 1982, explored part of the James Bay Lowland north of Hearst, Ontario. They used airborne magnetic reconnaissance surveying to delineate potential kimberlite bodies, followed by more detailed ground geophysical surveying (Janse et al., 1989; Reed and Sinclair, 1991). Although the 45 alnöite bodies identified were of no economic interest, this represents the first large-scale geophysical survey in Canada to find a field of “kimberlite-like” pipes.

In 1984, De Beers started an annual regional survey program north of the area explored by Selco and Esso in the James Bay Lowland. The combination of stream sediment sampling for indicator minerals (see box A, figure A-3) and airborne magnetic surveys led them to the Attawapiskat River area (Kong et al., 1999; figure 2 [24]). Drilling in 1988 and 1989 confirmed 16 kimberlites, ranging from 0.4–15 ha (1–37 acres), 15 of which contained diamonds.

Northeastern Ontario: Kirkland Lake. In the Lake Timiskaming area, De Beers drill tested the Guigues pipe (previously identified in the 1960s but not drilled) in 1981 and the Bucke pipe in 1983. Also in 1983, De Beers drill tested the A-4, AM-47,



Figure 5. The Batty kimberlite is part of the Somerset Island kimberlite field (figure 2 [3]), the first kimberlite field discovered in Canada. In the foreground are five smaller satellite pipes, with the main Batty pipe in the background. The dark kimberlites stand out in contrast to the light-colored carbonate host rocks where they are exposed at the surface of this nonglaciated area. Photo taken in July 1990 by B. A. Kjarsgaard.

and B-30 kimberlite pipes in the Kirkland Lake kimberlite field. In 1984, De Beers drilled the Morrisette Creek kimberlite, bringing to six the number of kimberlite pipes it had discovered in the Kirkland Lake/Lake Timiskaming area. For the first time, a major kimberlite field was discovered by design by a

Figure 6. The Mountain diatreme (dark color; ~850 m across) is an alkali basalt in which some microdiamonds were reported. Located in the Mackenzie Mountains of the Northwest Territories, this diatreme was the starting point for the exploration path that eventually led to the discovery of the Lac de Gras kimberlite field. Photo taken in June 1979, looking south, by A. E. Oldershaw.





Figure 7. Geologists Charles E. Fipke (left) and Dr. Stewart L. Blusson (right) are credited with discovering the first kimberlite in the Lac de Gras field, NWT. Photos courtesy of BHP Billiton Diamonds Inc.

diamond exploration company. Additional kimberlites were found in this area by Falconbridge in 1984 and 1987, Homestake in 1987, and Lac Minerals in 1987 (Sage, 1996). However, the diamonds recovered were small (the largest 0.17 ct), and the best grade reported for any kimberlite was 0.02 ct per tonne (Brummer et al., 1992b).

Saskatchewan. Diamond exploration in Saskatchewan started in 1987, when De Beers discovered diamondiferous kimberlite at Sturgeon Lake, about 40 km northwest of Prince Albert (Gent 1992a,b). Subsequent drilling, however, revealed that the kimberlite was a large glacially transported block (200 × 125 × 40 m). The few diamonds it contained were not economically significant (grade <0.01 ct/tonne; Scott Smith et al., 1996).

The De Beers activity prompted numerous companies to stake and evaluate claims in other parts of Saskatchewan (Lehnert-Theil et al., 1992). Most notable were joint-venture partners Uranerz Exploration and Mining Ltd. and Cameco Corp., both primarily uranium-mining companies. In 1988, they staked ground in the Fort à la Corne area, about 50 km east of Prince Albert (figure 2 [19]), based principally on regional geophysical maps published by the Geological Survey of Canada from 1967 to 1969 (Lehnert-Theil et al., 1992; Gent, 1992b). In late 1989, Uranerz and Cameco announced the discovery of seven kimberlite pipes, the first of many announcements over the next few years that would reveal that the Fort à la Corne kimberlite field is one of the largest in the world. Strnad (1991) noted that this find, based on the use of published government

aeromagnetic maps, represented the least expensive, fastest, and most productive approach ever applied to the discovery of a major kimberlite field.

Cordillera Region (and Eastward to Lac de Gras, NWT). When Superior Oil and Falconbridge Ltd. started exploration in the Cordillera in 1979, they did so in collaboration with Charles E. Fipke (figure 7, left) operating as C. F. Minerals Research Ltd. The exploration was directed by Hugo Dummett (Superior Oil). Dr. Stewart L. Blusson (figure 7, right), a long-time acquaintance of Fipke, assisted with sampling between 1981 and 1983 (Fipke et al., 1995b). In late summer 1982, Fipke and Blusson sampled, in secrecy, in the vicinity of Blackwater Lake (figure 8) after Dummett learned that De Beers had claims in that area. Fipke and Blusson made the important observation that the glacial tills in the Blackwater Lake area contained debris that suggested a source from rocks of the Precambrian Shield to the east. This was the beginning of the exploration that ultimately led to the discovery of the Lac de Gras kimberlite field.

By 1982, however, both Falconbridge and Superior had ceased exploration for diamonds in Canada. They transferred their assets (e.g., claims near Mountain diatreme and the Blackwater Lake data) to Fipke and Blusson, who then formed a 50–50 diamond exploration partnership known as the Blackwater Group. Without financial support from Falconbridge and Superior, however, they were unable to fund expensive exploration in the field and advanced instrumentation in the laboratory. In 1983, Fipke formed Dia Met Minerals Ltd., which went

public in 1984, to finance additional sample collection and analytical activities. Blusson worked closely with Fipke on conceptual, planning, and tactical aspects of the exploration and retained his financial interest in future discoveries.

For the rest of the decade, Fipke and Blusson explored eastward from Blackwater Lake into the “Barren Lands,” the name given to the vast (roughly 500,000 sq. mi. [1.3 million km²]), bleak, remote areas of northern Canada. The Barren Lands characteristically have few trees but numerous lakes and bare rock that is variably covered with a veneer of glacial deposits. In 1983, Fipke and Blusson discovered that the regional sampling procedures (i.e., obtaining indicator minerals primarily from stream sediment samples) that they had used previously in areas such as the Cordillera were ineffective in the region north of Lac la Martre. This is because the Barren Lands contain too many lakes and too few rivers, in an immature drainage network. The fateful decision was then made to sample the eskers shown on Quaternary geology maps published by the Geological Survey of Canada. By 1985, float plane- and helicopter-supported esker (and also till) sampling had taken them to Aberdeen Lake, far to the east of the Slave craton (again, see figure 8).

Interpretation of the results through 1985 showed that several highly anomalous indicator-mineral samples were abundant immediately north of Lac de Gras. One such sample contained ~10,000 indicator

minerals (combined pyrope, chrome diopside, and ilmenite; Krajick, 2001). Significantly, there were few such anomalous samples east of Lac de Gras. This suggested the source area had been located. Following extensive sampling, in 1989 Dia Met Minerals (usually under the name of others) began to stake claims in the Lac de Gras area that totaled nearly 350,000 ha by 1995 (Fipke et al., 1995b). All the while, Fipke and Blusson were only one step ahead of other diamond exploration programs, including those of De Beers and Selco. Further details of the exploration activities that led to Dia Met’s discovery of the Lac de Gras kimberlite field can be found in Fipke et al. (1995b), Duval et al. (1996), Boyd (1998), “The Ekati Diamond Mine” (1998), Frolick (1999), and especially Krajick (2001).

1990–2002: SUCCESS AT LAST

The 1990s will be remembered as the decade in which exploration activity led to the discovery of a great number of diamond-bearing kimberlites in Canada. These discoveries were made throughout the country, particularly in the NWT and Nunavut (a territory created from the NWT on April 1, 1999), but also in Ontario, Saskatchewan, Quebec, and Alberta. The world-class Ekati Diamond Mine™ opened in 1998, with the Diavik mine slated to begin production in early 2003 (figure 9). Several other projects are currently at an advanced exploration, feasibility, or permitting stage.

The Ekati Diamond Mine, Lac de Gras. In 1990, on the shore of a small lake called “Point lake” (a name chosen specifically to confuse other diamond explorers, as the real Point Lake lies 200 km to the northwest), Dia Met took a sample that yielded numerous indicator minerals with compositions indicating a diamondiferous kimberlite source (Fipke et al., 1995b). In September of that year, BHP formed a joint venture with Dia Met, Fipke, and Blusson—the NWT Diamonds Project—to explore, develop, and mine in the NWT. The agreement called for BHP to fund the diamond exploration program and, by spending up to US\$500 million on future mine construction costs on behalf of the consortium, BHP would earn 51% of equity in the project; the remaining equity would be Dia Met 29%, Fipke 10%, and Blusson 10%. The diamond exploration industry worldwide was startled because of the large amount of money involved, which valued the future mine, if any, at more than US\$1 billion. (Note that through-

Figure 8. This map shows the prospecting route, and major geographic locations mentioned in the text, that Fipke and Blusson took from the Blackwater Lake east to the Lac de Gras kimberlite field and beyond, in the Barren Lands, NWT. After Fipke et al. (1995b).





Figure 9. Numerous kimberlites are found within the Slave craton. Four important kimberlite fields in the craton are shown here: Central (or Lac de Gras, with the Ekati and Diavik mines), Southeast (with the Snap Lake and Gahcho Kué projects), Southwest, and North (with the Jericho project).

out the balance of this article, dollar amounts are given in U.S. dollars unless otherwise indicated as Canadian dollars [Can\$].) BHP also retained the responsibility to market future diamond production. Dia Met (under the supervision of Fipke) continued to manage the exploration project until July 1993 (J. A. Carlson, pers. comm., 2002).

In May 1991, BHP conducted geophysical surveys around and over "Point lake." That September, the joint venture drilled from the shore of "Point lake" and intersected kimberlite under the lake. Two months later, Dia Met announced this discovery and released the diamond recovery results (81 diamonds consisting of 65 microdiamonds and 16 macrodiamonds, from 59 kg of kimberlite; "The Ekati Diamond Mine," 1998). This announcement triggered one of the greatest staking rushes the world has ever experienced. By the end of 1992, at least 50 companies had staked almost 8 million hectares in the NWT (Levinson et al., 1992). Almost simultaneously, the methods of diamond exploration that were instrumental in finding the "Point lake" kimberlite (geophysical surveys, and the recognition and significance of kimberlite indicator minerals, combined with the use of eskers and tills for sampling) became widely known. By 1994, more than 80% of the Slave craton (~20,000,000 ha or 200,000 km²) had been staked by over 100 companies (Pell, 1994).

In early 1992, bulk sampling of the "Point lake" kimberlite yielded a diamond content of 0.63 ct/tonne and a stone value of <\$40/ct, which rendered this pipe subeconomic (Fipke et al., 1995b; "The Ekati Diamond Mine," 1998). That same year, however, nine additional kimberlites were discovered in the Lac de Gras area, including the Fox and Koala pipes (now in the current Ekati mine plan). The Panda and Misery pipes (currently in production; see figure 10) were discovered in 1993. By the end of 1994, a total of 39 kimberlites were known in the Lac de Gras area, most of which were under lakes (Carlson et al., 1995). At the same time, Fipke et al. (1995b) reported that all but one of these 39 kimberlites were diamond bearing.

By late 1993, it was clear that several kimberlites at Lac de Gras were probably economic, including the Fox (16.4 million tonnes of kimberlite; grade 0.3 ct/tonne; \$129/ct) and Koala (12.1 million tonnes of kimberlite; grade varies from 0.9 [pit] to 1.5 [underground] ct/tonne; \$138/ct) pipes (Kjarsgaard et al., 2002). Starting in 1993, the joint-venture partners

Figure 10. The Lac de Gras area contains the most important Canadian diamond deposits recognized so far. The locations of the economic pipes at the Ekati and Diavik mines are shown. The Panda pit (top, looking south, taken in August 2001) is the first of several economic pipes that will come into production sequentially over the life of the Ekati mine. In the immediate background, pre-stripping of the Koala pit can be seen. The development of the Misery pit is shown in the center photo, taken in August 2001. Both photos and the map are courtesy of BHP Billiton Diamonds Inc. At the Diavik mine (bottom, looking northwest, taken in September 2002), a retaining dike system has been constructed in the area surrounding the A-154N and A-154S pipes. Most of the water has been pumped out. Photo courtesy of Diavik Diamond Mines Inc.





Figure 11. Shown here in winter 1998, diamond mining at Ekati's Panda pit is done with large excavators and trucks. The truck in the background can carry 240 tonnes of rock. Courtesy of BHP Billiton Diamonds Inc.

went through what at the time was "the most exhaustive environmental, economic and social review in the history of Canadian mining" ("The Ekati Diamond Mine," 1998, p. 26), because the kimberlites are located in one of the most pristine and ecologically sensitive areas of Canada. Approval for the project was received in July 1996, after a review process involving many agencies, including the federal Department of Indian and Northern Affairs, the Government of the Northwest Territories, and four aboriginal groups. Construction of the mine began in January 1997. In September of that year, the NWT Diamonds Project was officially renamed the Ekati Diamond Mine, which today is trademarked. *Ekati* is the indigenous name for Lac de Gras, both of which mean *fat lake*. It refers to the abundant light-colored pegmatite stringers, veins, and dikes that cross-cut granites around the shores of the lake, like white fat running through caribou meat.

Construction of the Ekati mine was an amazing engineering and logistical feat in view of the numerous challenges presented by the remoteness of the area, the lack of permanent roads (a 475 km ice road is available from Yellowknife for only 8–10 weeks from mid-January to mid-April), the lack of other types of infrastructure (e.g., electricity), and the harsh climate (temperatures can drop to -50°C in the winter months). Yet, construction of a processing plant and supporting facilities, as well as prepara-

tion of the first kimberlite (figure 11), were completed on schedule in 21 months. Further, from the initial discovery of diamonds at "Point lake" in late 1991 through the feasibility studies and environmental approvals, it was only seven years to the official opening of the Ekati mine on October 14, 1998. This is a remarkable achievement. The mine employs about 680 people; 79% are residents of the NWT and 40% are aboriginal (Williams and Carlson, 2001).

The Ekati mine was located originally on a land lease of 10,960 ha, which has since been extended to 344,000 ha. It cost about \$700 million to construct. The Panda pipe was the first kimberlite mined (for details, see Johnson and Koivula, 1998; Krajick, 2001). In 1999, the first year of full production, this world-class mine produced 2.4 million carats (Mct) of rough diamonds worth \$408 million (table 2). This made Canada the world's seventh largest diamond-producing country in terms of both weight and value. Ekati's Panda pipe was the world's fourth most valuable diamond mine (Rombouts, 2000), exceeded that year only by Jwaneng (Botswana), Udachnaya (Russia), and Argyle (Australia). A variety of cuts and colors of polished diamonds from Ekati are shown in figure 12.

Throughout this period, the Ekati group continued to explore for additional kimberlite pipes in its claim area. By the end of 2001, they had identified a total of 146 pipes (table 3). Reserves at the start of mining were 72 Mct of rough diamonds and 66 million tonnes of kimberlite (average grade 1.09 ct/tonne), from several pipes (Johnson and Koivula, 1998, Gonzales et al., 2000). Current reserves are 52.8 Mct of rough diamonds from 58.2 million tonnes of kimberlite (average grade of 0.91 ct/tonne), from six pipes (BHP Billiton 2002 Annual Report). Initially,

TABLE 2. Diamond production from the Ekati Diamond Mine, 1998–2001.^a

Production	1998	1999	2000	2001
Carats	203,000	2,428,783	2,435,036	3,685,171
Total value				
Can\$	40,775,000	606,254,000	624,949,000	846,925,000
US\$	27,482,350	408,008,940	429,482,350	531,022,000
Value per carat				
Can\$	201	250	257	230
US\$	135	168	173	144

^a Source of data: Natural Resources Canada: www.nrcan.gc.ca/mms/efab/mmsd; 2001 figures are preliminary. Conversion rates for Can\$ to US\$: 1998 = 0.674; 1999 = 0.673; 2000 = 0.673; 2001 = 0.627.

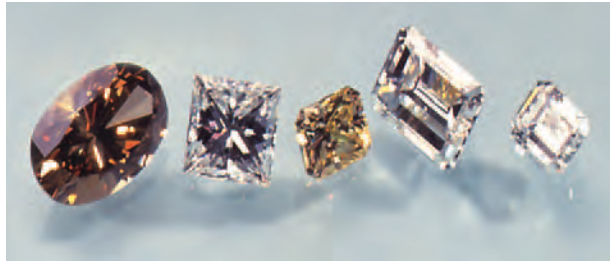


Figure 12. These diamonds from the Panda pit show a representative color range of diamonds produced at the Ekati mine. Courtesy of BHP Billiton Diamonds Inc.

Ekati held permits to mine the Panda, Koala, Misery, and Fox kimberlites. In December 1998, the company applied for additional permits to develop the Sable, Pigeon, and Beartooth pipes (Markovic, 1999). Resources identified to date will enable the mine to operate until at least 2016. In May 2001, BHP (now BHP Billiton) acquired Dia Met, raising its ownership in the Ekati Diamond Mine to 80%. Fipke and Blusson each retains 10% interest. Currently, the mine is producing from both the Panda and Misery pipes. There is underground production from a test mine at the Koala North pipe, and pre-stripping has begun at the Koala pipe (again, see figure 10), which will soon be the next major feed source (Janse, 2002).

The Diavik Project, Lac de Gras. Aber Resources Ltd. was one of the first companies to start staking claims in the Lac de Gras area in November 1991, shortly after Dia Met announced its success at "Point lake." This small Canadian exploration company staked claims south and east of the "Point lake" discovery and adjacent to the original Dia Met (now Ekati) claims (again, see figures 9 and 10). In June 1992, Rio Tinto agreed to finance Aber's exploration in exchange for the right to earn a 60% interest in certain Aber claims. That same year, Aber discovered eight kimberlites. The four most important kimberlites discovered by Aber (A-154 South, A-154 North, A-418, and A-21, which would constitute the future Diavik mine) were found in 1994 and 1995 in the shallow waters of Lac de Gras. In November 1996, Aber and Rio Tinto formed the Diavik Diamonds Project, a joint venture of Diavik Diamond Mines Inc. (60%; wholly owned by Rio Tinto) and Aber Diamond Mines Ltd. (40%; wholly owned by Aber Diamond Corp. [formerly Aber Resources Ltd.]). Diavik Diamond Mines is the manager of the project. Each participant retained the right to market its respective share of the diamond production independently.

Between 1994 and 1996, evaluation of the kimberlite grade and diamond value revealed that a mine was viable. When in full operation, the mine will produce approximately 6 million carats (Mct) annually for about 20 years, with an average value

TABLE 3. Number of kimberlites reported in Canada, as of September 2002.^a

Location	Number
NWT and Nunavut	
<i>Central Slave Craton (Lac de Gras, NWT)</i>	
Ekati claim area	146
Diavik claim area	58
De Beers (Hardy Lake)	20
Others	23
<i>Southeast Slave (NWT)</i>	
Snap Lake, Gahcho Kué, others	14
<i>Southwest Slave (NWT)</i>	
Carp Lake, Dry Bones Bay, others	15
<i>Far Northwest Slave (NWT)</i>	
Darnley Bay	10
<i>North Slave (Nunavut)</i>	
Jericho and Coronation Gulf area	23
<i>Victoria Island (NWT and Nunavut)</i>	
De Beers, others	17
Total for Slave Craton	326
<i>Churchill Craton (Nunavut)</i>	
Somerset Island	20
North Baffin Island and Brodeur Peninsula	5
Rankin Inlet	3
Total for Churchill Craton	28
TOTAL for NWT and Nunavut	354
Other Parts of Canada	
<i>Alberta</i>	
Buffalo Hills	36
Birch Mountains	8
<i>Saskatchewan</i>	
Fort à la Corne	74
Ontario	
Kirkland Lake	14
Lake Timiskaming	12
Attawapiskat	19
Kyle Lake	5
Quebec	
Lake Timiskaming	3
Otish Mountains	7
Wemindji	1
Manitoba	
Snow Lake–Wekusko	1
British Columbia	
Cross, others	4
TOTAL for other parts of Canada	184
GRAND TOTAL for Canada	538^a

^aThe number of kimberlites should be considered a minimum because it is not required that companies report their kimberlite discoveries.

of \$63/ct (table 4; based on 2000 valuation estimates). The Diavik kimberlites, like most in the Slave craton, are small (<3 ha), but their grades of ~4 ct/tonne (range 3.0–5.2 ct/tonne) are three to four times higher than those in most other major producing mines (Burgess, 2001; Kjarsgaard et al., 2002). Thus, when the Diavik mine is in full production, it will have the highest ore value (~\$252/tonne [$\63×4]) of any primary diamond mine in the world. This is particularly true for the A-154 South pipe, which averages 5.2 ct/tonne of diamonds valued at \$79/ct (for a total ore value of \$410/tonne).

After extremely detailed examination of the environmental aspects of the proposed \$830 million mine, Diavik obtained permits and licenses to begin construction in November 1999 ("Diamond Facts 2000/01," 2001). Since the kimberlites lie under the shallow waters of Lac de Gras, a retention dike system is required to mine them (again, see figure 10). During 2000–02, construction of the mine has proceeded ahead of schedule (figure 13). The mine plan calls for a two-year *ramp-up* period, starting in early 2003, before full production is achieved. Some of the stones recovered during the evaluation stage already have been cut and set in fine jewelry (figure 14).

Other Advanced Projects in NWT and Nunavut.

Both industry and government (e.g., Paget, 1999) agree that three projects in the NWT and Nunavut—Snap Lake, Gahcho Kué, and Jericho—are at an advanced stage of evaluation or development and may have the potential to become mines (table 4). However, actual construction of another mine has not yet begun.

Snap Lake Project. Indicator minerals in glacial till, as well as kimberlite boulders, were identified from the Snap Lake area (figures 2 [12] and 9) in 1995–96 by a joint venture between Winspear Resources (initially 57.3%, subsequently 67.76%) and Aber Resources Ltd. (initially 42.7%, subsequently 32.24%). In 1997, an outcrop of the diamond-bearing kimberlite dike, covered by a thin layer of till, was located on the west shore of Snap Lake. Subsequent sampling showed it to be potentially economic (table 4). The kimberlite, a shallow-dipping dike averaging 2.5 m thick, covers an area of 2.5 km² (Turner and McConnell, 2001).

Snap Lake would be the first entirely underground diamond mine in Canada, and as such will have a much smaller "footprint" than an open-pit mine; moreover, it is land based. It would also be

TABLE 4. Diamond mines under construction and advanced diamond projects^a in Canada.

Project name	Location	Owner	Reserves	Comments	References
Under construction					
Diavik	NWT	Diavik Diamond Mines (60%, Rio Tinto) and Aber Diamond Mines (40%, Aber Diamond Corp.)	25.6 million tonnes of kimberlite with ~4 ct/tonne (102 Mct) at \$63/ct	Production expected in early 2003; estimated to produce ~6 Mct/yr when in full production	www.diavik.ca, www.aber.ca
Advanced projects					
Snap Lake	NWT	De Beers (100%)	22.8 million tonnes of kimberlite with ~2.0 ct/tonne (~45 Mct) at ~\$100/ct	Kimberlite dike 2.5 m thick delineated over area 2.5 x 2.5 km; production scheduled to begin in 2006	Turner and McConnell (2001), Laurs (2001), Natural Resources Canada (2002)
Gahcho Kué (Kennady Lake)—Hearne and 5034 kimberlites	NWT	De Beers (51%), Mountain Province (44.1%), Camphor Ventures (4.9%)	Hearne: 6.86 million tonnes of kimberlite with 1.71 ct/tonne (11.7 Mct) at ~\$63/ct 5034: 12.5 million tonnes of kimberlite at 1.64 ct/tonne (~21 Mct) at \$65/ct	Deposit is subeconomic (by ~15%) at present	www.mountainprovince.com
Jericho	Nunavut	Tahera (100%); Rio Tinto has various options including 62.5% ownership	2.5 million tonnes of kimberlite with ~1.2 ct/tonne (3 Mct) at ~\$80/ct	Kimberlite grade and diamond value are satisfactory, but reserves are problematic	www.tahera.com
Victor	Attawapiskat, Ontario	De Beers (100%)	36.2 million tonnes of kimberlite valued at \$94/tonne; older reports indicate grade of 0.32 ct/tonne	Most advanced project outside of NWT	www.debeerscanada.com, Robertson (2002f), Wood (2002)

^a Advanced diamond projects are those at the evaluation or development stage. All values are in U.S. dollars.



Figure 13. This aerial view of the Diavik mine was taken in September 2002. The large (11 story) building in the center is the processing facility, where diamonds will be separated from the kimberlite host rock. The building to the lower right serves as the maintenance and administration center. In the lower left is the permanent accommodations facility, and above it (with the smoke stacks) is the power plant. Photo by Jiri Hermann; courtesy of Diavik Diamond Mines Inc.

the first diamond mine in the world to begin with an underground operation and not with an open pit. In 2000–01, De Beers acquired the property. It has since applied for regulatory approval to develop the mine (figure 15), with production scheduled to begin in 2006 (Lauris, 2001).

Gahcho Kué (Kennady Lake) Project. In 1995–96, a joint venture between Mountain Province Resources (now Mountain Province Diamonds) at 90% and Camphor Ventures at 10% discovered several kimberlites in the Kennady Lake area (figures 2 [13] and 9). In 1997, the property was optioned to De Beers, which can earn up to 60% interest by taking the project to commercial production; currently it has 51%. Eight diamondiferous kimberlites and several dikes and sills have been found on the property to date. The two most valuable kimberlites, Hearne and 5034, at present do not have the combined reserves and ore values (table 4) needed for economic development. However, De Beers continues to bulk sample these two pipes because some large (~10 ct; figure 16) stones have been recovered and because their grade and ore value is close to the economic threshold. De Beers is also exploring for other kimberlites in the area (www.mountainprovince.com).

Jericho Project. Joint-venture partners Lytton Minerals and New Indigo Resources discovered the Jericho kimberlite pipe (JD/OD-1; 1.2 ha) in 1994 in what is now part of the Contwoyto Lake kimberlite field (figures 2 [7] and 9). In 1999, these companies merged to form Tahera Corp. As reported on the

Tahera Web site (www.tahera.com), the deposit has yielded large stones (5–25 ct, including one 23.89 ct piece of gem-quality rough. Feasibility studies indicate that this kimberlite could produce a total of 3 Mct of diamonds (table 4) over eight years.

The economics of a mine based solely on the resources of the small JD/OD-1 pipe alone are marginal. However, they could be improved considerably with the discovery of additional resource tonnage, which is possible since the area contains other

Figure 14. Diamonds from the Diavik project (here, the larger stone is approximately 1 ct) have been set into attractive gold jewelry. Courtesy of Diavik Diamond Mines Inc.



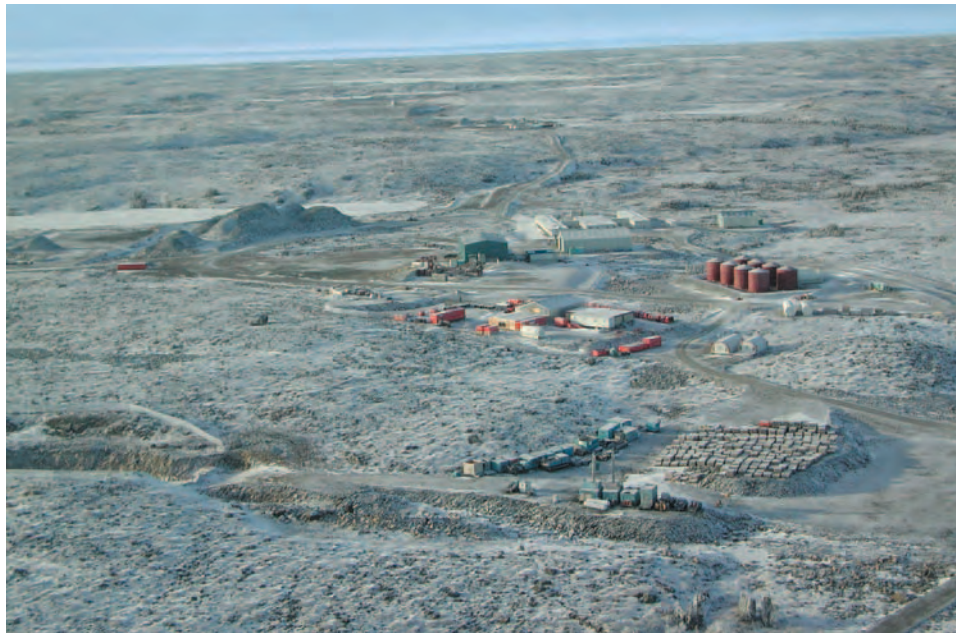


Figure 15. This image of the Snap Lake project, looking southwest, was taken in October 2001. The rock pile on the left rear is an ore stockpile, and the green building is the processing plant. The white buildings house offices and accommodations. The portal to the underground workings is located just to the left foreground of the processing plant, near the elongate orange container. Courtesy of De Beers Canada.

kimberlites (Janse, 2002). On the assumption that additional economic kimberlites will be found, Tahera is seeking regulatory approval for the development of the Jericho diamond mine. Rio Tinto, currently a joint-venture partner with Tahera, is the operator of the project and has certain valuable options with regard to the property (e.g., the right to market all production for the first five years). If Jericho is developed, it will be the first diamond mine in Nunavut.

Other Activities in NWT and Nunavut. As of September, 2002, at least 354 kimberlites were known in the NWT and Nunavut (table 3), several of which (in addition to the three advanced projects discussed above) are currently being evaluated. In view of this volume of discoveries, and the number of properties or fields in various stages of exploration and development within the Archean Slave craton, we can briefly mention only a few here.

De Beers discovered more than 40 kimberlites in the central and southern parts of the Slave craton during the diamond exploration boom of the 1990s, although the precise discovery dates have not been released. In addition to the eight kimberlites found to date in the Gahcho Kué area, these include 20 in the Hardy Lake area of the Lac de Gras field (35 km northeast of the Ekati mine; McKinlay et al., 1998), as well as four in the Carp Lake area and five in the Snare Lakes area (figures 2 [10/11] and 9; J. A. Armstrong, pers. comm., 2002).

In the northern part of the Slave province, De Beers discovered four kimberlites between

Contwoyto Lake (Jericho area) and the Coronation Gulf on the Arctic coast in the mid-1990s (figure 9; J. A. Armstrong, pers. comm., 2002). As geologists realized the diamond potential of this area, the entire region was staked, and exploration by Ashton, Rio Tinto, and many other companies laid the groundwork for additional kimberlite discoveries (Janse, 2001, 2002). At least 10 more kimberlites have been identified. Ashton found several diamondiferous pipes (e.g., Artemesia and Potentilla) near Kikerk Lake (figures 2 [6] and 9), but their grades turned out to be low (<0.2 ct/tonne). High expectations are now held for the diamondiferous Anuri and Anuri East pipes (about half way between Jericho and Kikerk Lake) found in 2001 by the Rio Tinto and Tahera joint venture, but their economic potential remains to be determined. Nevertheless, indicator minerals abound in the area and enthusiasm remains high for its diamond potential (Robertson, 2002b).

On Victoria Island (also part of the Slave craton; figure 2 [4]), exploration by De Beers and other companies has led to the discovery of 12 kimberlite pipes, half of which contain diamonds; De Beers withdrew from the area at the end of 1999 (Robertson, 2002e). With renewed interest in the northern part of the Slave craton, exploration on Victoria Island has also been re-invigorated, with five new diamondiferous kimberlites reported in 2002 (Robertson, 2002e).

The Ranch Lake pipe (figures 2 [8] and 9), which is the northernmost extension of the Lac de Gras kimberlite field, was discovered in 1993 by Tahera. Although this large kimberlite (12.5 ha, atypical for

the Lac de Gras field) is diamond bearing (0.2 ct/tonne; Janse, 2002), it was deemed uneconomic. It is currently being re-examined by BHP Billiton (www.tahera.com).

Activities Elsewhere in Canada. *Alberta.* Before 1990, a few diamond discoveries were reported from various locations in glacial tills and alluvial materials in Alberta (Morton et al., 1993; Dufresne et al., 1996), but none was substantiated. Consequently, the industry was startled when in early 1991 it learned that De Beers had staked 680,000 ha in the Peace River region of Alberta (Levinson et al., 1992). This was more than 1% of the total area of the province (66.1 million ha). The impetus for the staking was what are now called the Mountain Lake ultrabasic pipes (Leckie et al., 1997; figure 2 [17]). These pipes were later determined to be only weakly diamondiferous and, therefore, uneconomic.

Massive staking by numerous companies ensued almost immediately after the De Beers activities became general knowledge (the so-called first Alberta staking rush). During 1992 alone, about one-third of the province (22.4 million ha; Dufresne et al., 1996) was staked for diamond exploration; this rose to more than 50% by early 1994 (Kjarsgaard, 1997), primarily in western and southern Alberta. Extensive indicator mineral surveys in stream sediments and tills were conducted throughout the province, but no kimberlites or other diamond-bearing rocks were found in the early to mid-1990s. By 1995, Alberta's luster as a diamond exploration area had diminished greatly; only about 1.6 million ha were staked that year (B. Hudson, pers. comm., 2002). Subsequently, De Beers (and many other companies) relinquished their claims, and the lands reverted to the Alberta government.

Alberta is an important producer of oil and gas, and geophysical (mainly seismic and aeromagnetic) surveys are routinely conducted as part of such exploration programs. In 1995, Alberta Energy Co. Ltd. (now merged into EnCana) acquired high-resolution geophysical data for parts of northern Alberta. These data revealed unusual features that bore no relation to petroleum deposits, and were interpreted as potentially related to kimberlite intrusions. This information was made available to Ashton, and in October 1996 Ashton formed a joint venture with Alberta Energy (42.5%) and Pure Gold Resources (15%), which staked large areas in the Buffalo Hills region (figure 2 [16]). Drilling of the anomalies started in January 1997, and by early



Figure 16. This parcel of rough diamonds was recovered from Gahcho Kué (5034 pipe). The largest stone weighs 9.9 ct and is of good gem quality. Courtesy of Mountain Province Diamonds Inc.

March 11 kimberlites had been found. This set off Alberta's second staking rush, with 37.2 million ha (372,000 km²) staked in 1997 alone (B. Hudson, pers. comm., 2002). Claim staking by about 30 companies, including De Beers and Rio Tinto (Natural Resources Canada, 2000), occurred in the northern and central parts of the province. Rio Tinto subsequently discovered the Birch Mountains kimberlite field (figure 2 [15]), but withdrew from the area when it proved uneconomic.

By early 1999, Ashton had outlined the Buffalo Hills kimberlite field, which included 32 (now 36; table 3) kimberlites, about 60% of which contained diamonds. S. M. Carlson et al. (1999) provide geologic details of this area, including descriptions of the kimberlites and the diamonds recovered. Some of these kimberlites are large (up to 45 ha), and some of the diamonds are of good quality and weigh up to 1.3 ct. Nevertheless, as the 1990s came to a close the Buffalo Hills kimberlite field was generally thought to be subeconomic, although Ashton and others continued to explore in the area.

After 10 years of disappointments in Alberta, there were great expectations when Ashton found the K252 kimberlite in the Buffalo Hills in 2000. The grade of this pipe (0.54 ct/tonne) and the quality of its diamonds (figure 17) were the best so far discovered in the province. However, in early 2002 Ashton

announced that the pipe was too small for further consideration. Also in early 2002, BHP Billiton acquired options in the Calling Lake region, about 150 km southeast of the Buffalo Hills area (Robertson, 2002a). The Calling Lake tills abound with indicator minerals (e.g., garnets), for which a source has yet to be identified. This activity has attracted the attention of other diamond exploration companies, which ensures that exploration for diamonds in Alberta will continue for the foreseeable future.

Saskatchewan. Following the 1989 confirmation of seven kimberlite pipes in the Fort à la Corne area (figure 2 [19]), joint-venture partners Uranerz and Cameco drilled 12 additional kimberlites by 1991 (Lehnert-Thiel et al., 1992). In 1992, after De Beers joined the joint venture, a major drilling program resulted in the confirmation of 20 new kimberlites in 1992–93 and established that a high percentage were diamondiferous. The addition of Kensington Resources to the joint venture in 1995 led to further drilling, and the identification of an additional 31 kimberlites by 1997 (69 of the original 71 geophysical targets outlined in 1989 proved to be kimberlites). Four additional kimberlites have been found by other companies. The pipes range from 2.7 to 184 ha and contain from 3 to 675 million tonnes of kimberlite; some are extraordinarily large by world standards (Robertson, 2002g).

Diamonds have been recovered from more than half of the Fort à la Corne kimberlites, and close to

70% of them are gem quality (Jellicoe et al., 1998). *Exploration* and *modeled grades* range from <0.01 to about 0.3 ct/tonne. A significant problem hindering evaluation of the Fort à la Corne kimberlites is that they are overlain by up to 100 m of glacial till and unconsolidated sediments, which makes it more difficult and expensive to obtain the appropriate large samples.

In 2000, De Beers carried out an in-depth resource evaluation at Fort à la Corne, which was followed by a mini-bulk sampling program on two high-priority bodies (141 and 122). A larger mini-bulk sample was taken from body 141 in 2001, with an exploration grade of ~0.05 ct/tonne, modeled grade of 0.08–0.19 ct/tonne, and *modeled stone value* of \$148/ct (www.kensington-resources.com; Robertson, 2002g; Janse, 2002). Also in early 2000, Shore Gold started an extensive core drill program at its diamondiferous Star kimberlite. Recent mini-bulk sample results are similar to those for body 141 (www.shoregold.com) and have led to plans for bulk sampling. Like 141, the Star kimberlite is extremely large (estimated >500 million tonnes).

Ontario. For most of the 1990s, events in the NWT eclipsed diamond activities in Ontario. Nevertheless, in 1995, microdiamonds were found in a mafic dike exposed in a road cut along the Trans Canada Highway, 35 km north of Wawa (figure 2 [25]; Thomas and Gleason, 2000). Subsequent work by several small companies (e.g., Spider Resources) located additional dikes over a wider area. The diamonds, although abundant in places, are small, with the largest found 0.1 ct (Janse, 2001). As exploration activity increased in 2000–02, an extensive area of Archean diamond-bearing volcanic rocks was discovered in the immediate region of the mafic dikes. These unusual volcanic rocks are currently being sampled by exploration companies Pele Mountain Resources and Band-Ore, with assistance from De Beers and Rio Tinto, respectively, to determine their economic potential (Robertson, 2002c).

Elsewhere in Ontario, five diamond-bearing kimberlites have been found in the Kyle Lake area of the James Bay Lowland (Janse, 1995b; figure 2 [23]), but the one with the best grade is too deeply buried to be considered economic at this time. In the adjacent Attawapiskat kimberlite field (figure 2 [24]), evaluation of the Victor kimberlite began in 1998. The Victor kimberlite comprises two pipes that coalesce at the present surface with an area of ~15 ha. With a quoted ore value of \$94/tonne (Robertson,

Figure 17. These rough diamonds were selected from a 12.54 ct parcel recovered from a 22.8 tonne bulk sample at the K252 pipe in the Buffalo Hills, Alberta. The largest stone in the upper left is 2.9 mm long. Courtesy of Ashton Mining of Canada.



2002f), Victor has the potential to host Canada's first diamond mine outside the NWT (table 4). However, it is in a remote area, the grade is highly variable, and the geology is complex (Wood, 2002).

Quebec. Several ultrabasic dikes (up to 3 m wide) were discovered in 1991 outcropping on cliff faces in the Tornat region of northern Quebec (figure 2 [32]). In 1999, Twin Mining determined that three of the dikes contained diamonds. Subsequent exploration found another set of dikes about 10 km to the southwest (Moorhead et al., 2000). Some can be traced for ~37 km (Janse, 2002). At present little work is being done in the area and the dikes are considered uneconomic. However, at least 50 companies are currently exploring in Quebec. By mid-2002, seven diamond-bearing kimberlites had been found by partners Ashton Mining and SOQUEM in the Otish Mountains (figure 2 [30]), thus defining a new kimberlite field (Robertson, 2002d). A diamondiferous kimberlite dike was found in early 2002 by Majescor Resources at Wemindji, in the Quebec side of the James Bay Lowland (figure 2 [31]).

Other Jurisdictions. Since 1990, limited diamond exploration has been conducted in British Columbia, the Yukon Territory, Labrador, and Manitoba (see, e.g., Natural Resources Canada, 2000), but with no success to date. Nevertheless, in the entire country only the three Maritime provinces (Nova Scotia, New Brunswick, and Prince Edward Island) did not have any diamond exploration activity.

ECONOMIC ATTRIBUTES OF CANADIAN DIAMOND DEPOSITS

Diamond Exploration and Infrastructure. Diamond exploration in Canada has been ongoing for four decades, and in recent years virtually all major diamond exploration companies have had a significant presence there. For example, in 2001 De Beers spent 40% of its \$73 million global exploration budget in Canada (Robertson, 2002f), whereas BHP Billiton spends 25% of its total exploration budget on diamonds, most of which is in Canada (Janse, 2002). As of the end of September 2002, 538 kimberlites had been discovered (table 3), about 90% in the last decade. More than half of the Canadian kimberlites are diamondiferous, which far exceeds the world average of about 20% (A. J. A. Janse, pers. comm., 2002). Historically, only about 1% (i.e., about 50) of the world's kimberlites have been economic. In

Canada, however, the percentage is significantly higher, especially in Lac de Gras where 12 (~5%) of the 247 kimberlites are economic.

During the 1990s, approximately Can\$900 million was spent on diamond exploration and deposit evaluation in Canada (Natural Resources Canada, 2000, 2002), and more than twice that amount on the construction of the Ekati and Diavik mines. Exploration reached its peak in 1994–96, when about 150 companies were involved and about 200,000 km² in the Lac de Gras area were staked (Duval et al., 1996). During this period, an average of Can\$146 million was spent annually for diamond exploration, with 88% of that spent in the NWT. By 1997–99, only about 50 exploration companies were active in Canada, with expenditures down to an average of Can\$113 million annually. Of this, 79% was spent in the NWT, but Alberta and Ontario received relatively more exploration attention. Preliminary data for 2000 and 2001 indicate that an average of Can\$98 million was spent annually on diamond exploration, of which 67% was spent in NWT and Nunavut, with significant increases in Ontario and Quebec relative to the rest of the country (Natural Resources Canada, 2000, 2002).

Economic Parameters of the Lac de Gras Kimberlites in a Worldwide Context.

The small size of most of the Lac de Gras kimberlite pipes, as compared to economic diamond mines elsewhere in the world, is evident from figure 18. Eight of nine Lac de Gras kimberlites (selected from the Ekati and Diavik mine plans) are 5 ha or less, significantly smaller than active diamond mines elsewhere, which are all >10 ha in size. However, five of these nine Lac de Gras kimberlites (Misery and four Diavik pipes) have exceptional diamond ore grades (3.0–5.2 ct/tonne; Kjarsgaard et al., 2002) as compared to other active diamond mines (figure 19). The only kimberlite that had a higher grade (variably reported as 6 ct/tonne by Janse, 1993, and 11 ct/tonne by Duval et al., 1996) is the mined-out Internationalaya pipe in Russia.

There is a wide variation in the average stone value (quality) for the individual Lac de Gras kimberlite pipes. Ekati's currently mined Panda pipe has an average stone value of ~\$170 per carat (table 2). From exploration parcels, BHP Billiton has reported average *exploration stone values* of >\$100 per carat for the Koala and Fox pipes, which are clearly in the upper echelon of stone values from active worldwide mines (figure 20). It is because of the combination of very high grades coupled with

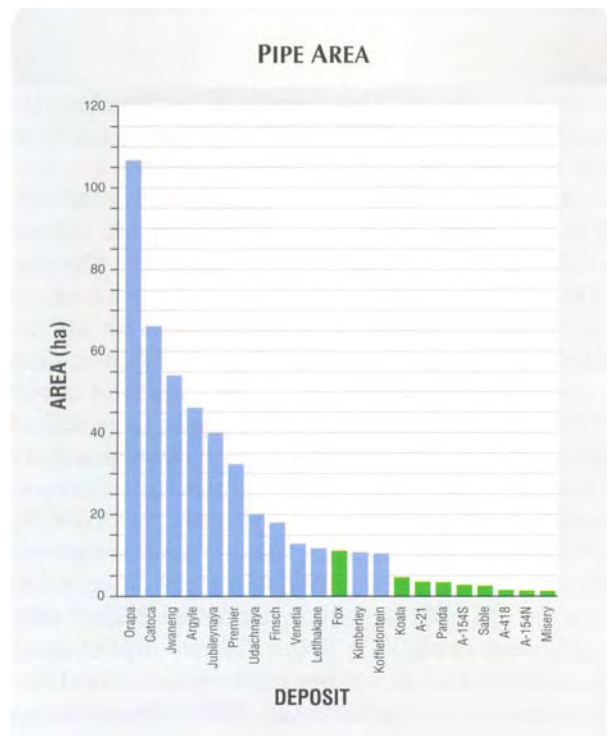


Figure 18. In general, the surface area of kimberlite pipes in Canada's Lac de Gras area (green) is much smaller than that of the other pipes worldwide that are being mined actively (blue). Data sources: Ekati—J. A. Carlson (pers. comm., 2002); Diavik—Graham et al. (1999); Udachnaya, Jubileynaya, and Argyle—Janse (1993); southern African—Janse (1996).

high stone value that the Panda pipe has a mine ore value of >\$150/tonne (figure 21), higher than the Jwaneng (\$138/tonne) and Udachnaya (\$112/tonne) kimberlites. Further, the exploration ore value for the A-154S and A-418 kimberlites also exceeds \$150/tonne. In summary, the Lac de Gras pipes tend to be smaller, low-tonnage bodies that may have exceptionally high diamond grades, coupled with quite variable (moderate to high) stone values. Thus far, development of the Ekati and Diavik mines in the Lac de Gras field has been economically viable only because each encompasses multiple small pipes that are close together and provide sufficient tonnage for a 15–20 year mine life.

Contribution of Canadian Rough Diamonds to World Supply. From 1999 (the first year of full production at the Ekati mine) to 2001, total world annual production increased from ~110 Mct in both 1999 and 2000, to ~119 Mct in 2001. This production was valued at \$7.2 billion in 1999 and ~\$7.9 billion in both 2000 and 2001 (Rombouts, 2000,

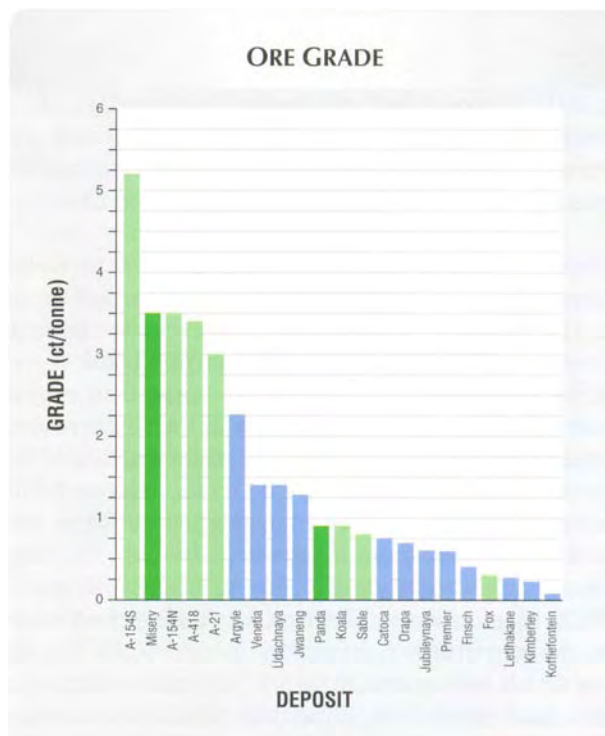


Figure 19. Relative to other worldwide kimberlites being mined actively (blue), many of the Lac de Gras kimberlites (green) have high diamond ore grades. The ore grade for Panda and Misery is shown in dark green, because they are being mined actively. Other Canadian pipes are shown in light green, since their data are based on exploration grade. Data sources: Ekati—Kjarsgaard et al. (2002); Diavik—www.diavik.ca; Udachnaya, Jubileynaya, Catoca, and Argyle—Rombouts, (2002); others—De Beers Consolidated Mines (2001).

2001, 2002). Thus, the average value per carat of world production varied between \$71/ct and \$66/ct in the period 1999–2001. The ~2.4 Mct produced from Ekati's Panda pipe in 1999 and 2000, at ~\$170/ct, had an annual total value of ~\$415 million (table 2). This was about 2% by weight and 5% by value of world production.

The Panda pipe, however, is approaching the end of its open-pit mine life, so the Ekati mine will soon draw ore from several kimberlite pipes with different grades and values per carat. The production numbers will change as these new pipes are brought on stream. In 2001, a larger number of carats (~3.7 Mct) was produced from Ekati with a lower value per carat (~\$144) compared to the two previous years. This was caused by drawing ore not only from the Panda pipe, but also from the Misery pipe, which, according to BHP's 2000 Annual Report, has a higher diamond grade (3.3 ct/tonne, only stones >1.5 mm) but a lower



Figure 20. A wide variation in average rough diamond value is shown for the Lac de Gras kimberlites. Colors as in figure 19, and data sources as per figure 18.

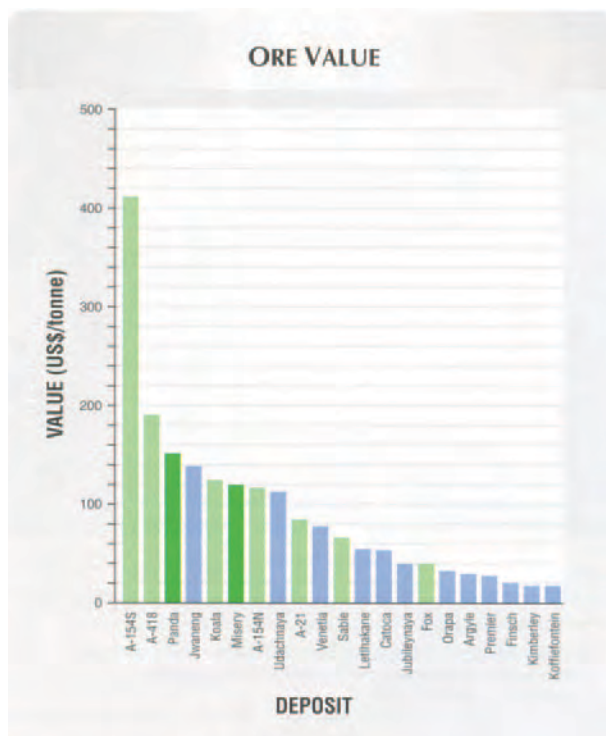


Figure 21. Some of the Lac de Gras kimberlites are inferred to have higher ore values (determined by diamond grade multiplied by average diamond value) than other active worldwide diamond mines. Colors as in figure 19, and data sources as per figure 18.

value per carat (\$34). Production of rough in 2002 is expected to reach ~4 Mct due to a greater contribution of ore from the higher-grade Misery pipe (Kjarsgaard et al., 2002).

When the Diavik mine reaches full production, by late 2003 or early 2004, about 6 Mct per year will be added to world production at an average value of ~\$63/ct (Kjarsgaard et al., 2002). In the first 10 years of production, Diavik is expected to produce about \$475 million annually, because of the relatively high value (\$79/ct) of the diamonds from the A-154 South pipe. This is expected to drop to <\$375 million per year when production is primarily from the other three pipes. Primary diamond deposits (such as the A-154 South kimberlite) that produce such large amounts of diamonds are rare. Currently only six such mines worldwide produce more than 3 Mct per year: Argyle (Australia), Orapa and Jwaneng (Botswana), Udachnaya and Jubileynaya (Russia), and Venetia (South Africa).

By the end of this decade, new production may also be coming from at least one of the several advanced projects listed in table 4. Moreover, the original (1997) Ekati mine plan anticipated that the current daily processing of 9,000 tonnes of ore would be doubled to 18,000 tonnes beginning in 2008

(Johnson and Koivula, 1998; Kjarsgaard et al., 2002).

Table 5 lists the contribution of the world's eight most important countries to rough diamond production by weight and value for 2001 (Rombouts, 2002). In 2001, Canada was the world's seventh rough diamond producer by weight and fifth by value. By the end of 2003 (or at least in 2004), Canada's annual production from two mines (Ekati and Diavik) is expected to be ~10 Mct valued at ~\$1 billion, thus elevating Canada to the world's sixth most important rough diamond producer by weight and fourth by value (8% and 10%, respectively), just slightly behind South Africa in both categories.

SELLING, CUTTING, AND BRANDING OF CANADIAN DIAMONDS

Sales. In May 1998, BHP (now BHP Billiton) Diamonds Inc. was appointed sales representative for the Ekati mine for five years. Sales commenced in January 1999 through the BHP Diamonds Inc. sales office in Antwerp, Belgium. A sorting and valuation facility, located near the Yellowknife airport, opened in February 1999. The facilities are used for cleaning,

TABLE 5. Production of rough diamonds by weight and value worldwide in 2001.^a

Country	Carats	Value of production (US\$)	Unit value (US\$/ct)
Botswana	26,416,000	2,193,870,000	83
Australia	26,070,000	293,700,000	11
Russia	20,500,000	1,650,000,000	80
Democratic Republic of Congo	19,637,000	496,310,000	25
South Africa	11,301,000	1,144,655,000	101
Angola	5,871,000	803,145,000	137
Canada	3,685,000	530,640,000^b	144
Namibia	1,502,000	322,340,000	215
All others	3,749,000	450,400,000	120
World total	118,731,000	7,885,060,000	66

^a From *Rombouts (2002)*.

^b Value of production for Canada differs slightly from that presented in table 2 because of variations in the factor used to convert Canadian to U.S. dollars.

sizing, and basic sorting of the rough diamonds, as well as for the division of product for various marketing channels, government valuation, and sales to NWT manufacturers. Rough diamonds from the Ekati mine are valued before export so that royalties (14% of the price received for the diamonds minus permitted expenses) can be estimated and paid to the federal government when the diamonds are sold.

The current marketing program for Ekati diamonds involves sales through three separate channels. Approximately 10% by value, in specific sizes and qualities, is sold to three cutting and polishing factories operating in the NWT. Based on a three-year agreement that became effective in January 2000, 35% of the run-of-mine production has been sold to the De Beers Diamond Trading Company (formerly Central Selling Organisation). The remaining 55% is sold through the Antwerp office to international manufacturers and traders. Currently, most of the sales from the Antwerp office are made in broad assortments to a limited number of regular customers on a five-week cycle. Remaining sales are made in smaller, more specific assortments to dealers and manufacturers on a nonregular basis.

In September 2002, BHP Billiton announced that it would not renew the marketing arrangement with De Beers after the final 2002 shipment of rough diamonds. BHP Billiton will now sell 90% of its production to international manufacturers and traders through its Antwerp office. It will use the share previously sold to De Beers to

pursue value-added opportunities.

Diamonds from the Diavik mine will be sorted and valued in a separate facility at Yellowknife, and will follow different routes to the cutting centers. After the production is divided in Yellowknife, Rio Tinto's portion (60% of the total) will be sold through a facility in Antwerp, whereas Aber's portion (40%) will be sold out of a rough diamond sorting facility in Toronto. Most significant is that Aber has a marketing arrangement with Tiffany & Co. (which also, at 14.9%, is Aber's largest shareholder), whereby Aber will supply Tiffany with a minimum of \$50 million of rough diamonds in certain specific categories for a 10-year period. The remainder of Aber's share of the Diavik production (possibly up to \$170 million) will go to an Antwerp-based marketing joint venture between Aber and Antwerp diamantaire and manufacturer Overseas Diamonds N.V., for placement in the diamond markets and cutting centers. However, entry into jewelry manufacturing at a later date is not excluded (Aber Diamond Corp., 2002).

Cutting Diamonds in the NWT. The Government of the Northwest Territories (GNWT), the aboriginal people, and the federal government of Canada are committed not only to developing diamond mines with due regard to the environment and indigenous cultures, but also to adding value to the diamonds within Canada (Paget, 1999). These value-added opportunities include cutting and polishing, jewelry manufacturing, and tourist-related activities ("Diamond Facts 2000/01," 2001), which have been initiated primarily by the GNWT. Although BHP Billiton has agreed to provide up to 10% by value of Ekati's production to three NWT manufacturers (Paget, 1999), currently only a 7% allocation is used (Janse, 2002). Based on a "memorandum of understanding" between the GNWT and Diavik Diamond Mines, a supply of rough diamonds from forthcoming Diavik production also will be manufactured in the NWT ("Diamond Facts 2000/01," 2001). An in-depth review of the NWT cutting and polishing industry can be found in Smillie (2002).

One cutting and polishing facility (Sirius Diamonds Ltd.; figure 22) opened in 1999, and two others (Deton'Cho Diamonds Inc. and Arslanian Cutting Works NWT Ltd.) opened in 2000. Manufacturers are attracted to Yellowknife by the very generous financial and other incentives offered by the government to companies that create jobs there (for details, see Even-Zohar, 2001; Smillie,

2002). By world standards these cutting facilities are small, currently employing a total of 60–80 people. They specialize in producing faceted diamonds from 30 points to 1 carat (see, e.g., figure 23). In view of the high labor and related manufacturing costs in Canada relative to most other cutting centers, the diamond rough given to the Yellowknife factories is typically of a higher quality. It has been projected that, in five years, 200 cutters in these three factories will process some 5,000 carats of rough per month (Even-Zohar, 2001). Tiffany is currently constructing a manufacturing facility in Yellowknife, where it intends to cut one-quarter of its share of diamonds from the Diavik mine (Robinson, 2002). Diamonds mined in Canada are popular, and premiums of up to 20% have been reported (Even-Zohar, 2001). This has led to the serious suggestion (Waytiuk, 2001) that retailers add to the established “4 Cs” a fifth “C”—“Canadian.”

Branding Canadian Diamonds. Although Argyle marketed “Champagne” and “Cognac” diamonds in the early 1990s, and some manufacturers considered branding as an option to offset shrinking profits in the mid-1990s (Scriven, 1997), the branding of diamonds did not become a significant marketing tool until the late 1990s. By that time, though, many diamond brands had been introduced, frequently with price premiums of up to 15%. Drucker (2000) lists 22 different brands, many with laser-inscribed girdles and/or certificates, almost all of which are based on specific cuts or shapes. Under a pilot program that started in 1999, De Beers provided loose branded “De Beers” diamonds to a retail chain in England (Sielaff, 1999). Brand naming an otherwise generic product, such as diamond, is a proven way of enticing customers, as evidenced by the success of other luxury goods such as watches and clothing (Scriven, 1997). The brand name implies quality, distinctiveness, prestige, and confidence.

Canadian diamonds are unique in that they are the only diamonds that are branded on the basis of origin. Because of the “conflict diamond” issue in recent years, origin has become an important consideration. In 1999, Sirius Diamonds became the first to market diamonds as being mined and cut in Canada. Their “branded” diamonds are laser-inscribed with a polar bear and a serial number, and come with a certificate. Soon other brands, identified with a snowflake, maple leaf, beaver, or other logos representative of Canada, entered the market (see, e.g., figure 24).



Figure 22. These diamond polishers are working at Sirius Diamonds in Yellowknife, NWT. Sirius was the first cutting facility to open in Canada’s Far North, to manufacture diamonds from the Ekati mine. Photo © Tim Atherton, 2000.

The Government of the NWT introduced a program to certify branded diamonds as being mined, cut, and polished in the Northwest Territories. The program, the only one of its kind in the world, has a strict monitoring system that follows the diamond from

Figure 23. The diamond-cutting factories in Yellowknife typically produce diamonds ranging from 30 points to one carat. The stones shown here were fashioned by Sirius Diamonds; photo © Roy Tanami/Ursus.



mine to factory (in Yellowknife). Since November 2000, Canadian Arctic™ diamonds have come with a certificate signed by the Premier of the NWT attesting to their authenticity (“Diamond Facts 2000/01,” 2001). Other examples of NWT-branded diamonds include the Loon™ diamond in Canada, and the Tundra™ and Canadia™ diamonds in the U.S.

EFFECTS OF CANADIAN GOODS ON THE DIAMOND PIPELINE

Since it was established in 1935, the De Beers Central Selling Organisation (CSO) has played a key role in maintaining stability in the diamond market through the allocation of rough diamonds to the cutting centers (i.e., the single-channel marketing system). For most of this period, there were relatively few major producers, and they were amenable to selling their rough diamonds through the CSO. However, the influx of rough diamonds from various sources over the period 1991–96, and the marketing of Argyle (Australia) diamonds independently from De Beers starting in 1996, has put a severe strain on the De Beers pipeline (Sevdermish et al., 1998). In July 2000, De Beers formally announced that it would end its efforts to control world diamond supply (see, e.g., Boyajian, 2000). Nicholas Oppenheimer (2002, p. 30) subsequently acknowledged that the Canadian diamond discoveries contributed to this monumental decision: “As new sources of supply opened up—particularly in Canada—it became evident that that role could not be sustained.” In 2001, De Beers’s share of the rough diamond market slipped to 57% from its historical ~80% (Even-Zohar, 2002).

With De Beers’s changed role, all rough diamond

producers are now competing for market share. Strategies are being developed to cope with the new competition. The one preferred by current and prospective Canadian producers is vertical integration (a supply chain) from the mine to the retail consumer, that is, a Canadian pipeline. Even-Zohar (1999, p. 35) predicted, “Ultimately, competitive dominance will only be achieved by an entire supply chain. Competition battles will be fought supply chain against supply chain.”

Ekati has a multi-faceted approach to its distinctive pipeline. Not only does it sell to the manufacturers mentioned above, but it also sells a small percentage as branded and certified “Made in Canada” diamonds, laser-inscribed with a maple leaf logo, through a limited number of primarily Canadian retailers (polishing is done by contract manufacturers). BHP Billiton, the majority owner of the mine, also sells polished (“Aurias”) diamonds over the Internet (“Ekati to ‘brand’ its diamonds,” 2001).

CONCLUSIONS

The first 60 years after Hobbs (1899) suggested the likelihood that diamonds would be found in Ontario saw no organized diamond exploration, in part because of the logistical difficulties of working in those parts of the Canadian sub-Arctic and Arctic that contained the most favorable geologic terrain. Exploration formally started in 1960, and activity expanded through the 1980s into extremely remote areas. Starting in the 1980s, new scientific concepts, mainly those involving airborne geophysical surveys, glacial geology, and the use of indicator minerals, were incorporated into many of the exploration programs.

Figure 24. Unlike most other diamonds, Canadian diamonds are typically branded to show their country of origin. Many organizations brand their Canadian diamonds by inscribing logos such as the polar bear (Sirius Diamonds) on the left, or a maple leaf and the name of the retailer (center, Henry Birks & Sons), or the name of the mine (far right), usually in combination with a registration number. Photomicrographs by Mitchell Moore; magnified (left to right) 55×, 30×, and 50×.





Figure 25. Canadian diamonds are now being featured by jewelry designers and retailers. The center diamonds in these three rings have all been inscribed with the Sirius polar bear logo. The center diamonds are, from left to right, 0.81, 0.42, and 0.51 ct; all are set in 18K yellow and white gold or (far right) platinum. Photo © 2002 Peter Kangas Jewellers Ltd.

The breakthrough came in 1991, when diamond-bearing kimberlite was discovered at “Point lake.” Since this discovery, Canada has become a focal point for much of the world’s diamond exploration. Geologists have benefited from significant advances in technological methods, with the result that 538 kimberlites, over half of which are diamondiferous, are now known throughout the country; 90% have been discovered in the last decade. New discoveries continue to be announced, albeit at a slower rate than in recent years.

Canada’s first diamond mine, Ekati, began production in late 1998. After Canada’s second mine, Diavik, reaches full production (possibly in late 2003), annual rough diamond production from the

two mines will be ~10 Mct valued at ~\$1 billion. This will rank Canada as the sixth most important producer in the world by weight and fourth by value. It appears likely that additional mines (e.g., Snap Lake, Gahcho Kué) will be in production by the end of this decade (barring unforeseen economic or other events). Canada has added a new level of competition to other segments of the diamond business, ranging from the cutting and polishing of higher-value stones, to branding, and the retailing of “Canadian diamonds” in fine jewelry (figure 25). As these aspects of the Canadian diamond industry continue to evolve, Canada will play an increasingly important role in the world diamond market.

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“DIFFUSION RUBY” PROVES TO BE SYNTHETIC RUBY OVERGROWTH ON NATURAL CORUNDUM

By Christopher P. Smith

A relatively new production of red corundum, reportedly from Bangkok, has been offered for sale in recent years. Although the producers claimed that these stones were red diffusion-treated corundum (i.e., a shallow coloration induced by the lattice diffusion of chromium), the surface layer is actually a synthetic ruby overgrowth on natural colorless to near-colorless corundum. The overgrowth layer, after recutting, typically ranged from <0.1 to 0.3 mm thick. This material can be distinguished from red lattice diffusion-treated corundum by the presence of a boundary plane and two different types of inclusion features: those that occur in the natural corundum core and those present only in the synthetic overgrowth. This product demonstrates that as treatment techniques continue to evolve, the distinction between natural, treated, and synthetic corundum may become increasingly difficult to define.

A relatively new product seen occasionally at gem shows since 1998 has been marketed as “Diffusion Ruby” (figure 1). When the author examined several specimens of this strongly colored red corundum, it became clear that the shallow red coloration was not the result of a diffusion treatment—that is, the diffusion of chromium into the lattice of the host corundum (lattice diffusion) to induce a shallow red color layer at the surface of an otherwise pale or near-colorless sapphire. Rather, it was an overgrowth of synthetic ruby on top of colorless to near-colorless natural corundum. A similar product was grown experimentally by J. Lechleitner of Innsbruck, Austria, in the early 1980s

(Bank, 1983; Schmetzer and Bank, 1988); however, this material was never produced in commercial quantities. The present article describes the gemological characteristics that will distinguish this new commercial product from red lattice diffusion-treated corundum as well as from natural rubies.

MATERIALS AND METHODS

In the course of conversations with vendors who were selling stones labeled as “Diffusion Ruby,” the author made a cursory examination of approximately 50 specimens, macroscopically and with a 10× loupe. Eleven faceted samples were selected from two of the vendors as those best representing the various characteristics observed in the larger group. They ranged from 0.80 to 1.84 ct (see, e.g., figure 1). One of these vendors indicated that his supplier was the originator of the treatment, which was done in Bangkok (J. Boyle, pers. comm., 1998).

Three of the samples were subsequently repolished to permit analysis of the surface layer and the main body of the stones. One sample was recut and repolished into a 2 mm slice, to produce parallel windows that bisected the stone along its length, whereas the other two samples were repolished at one end of each stone to more clearly differentiate the natural core from the synthetic outer layer.

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All tests were conducted on all 11 samples. Standard gemological instrumentation was used to record the refractive indices, birefringence, optic character, pleochroism, and optical absorption spectra (desk-model spectroscope). Refractive index readings were taken on the table and pavilion facets. Specific gravity was determined hydrostatically. A binocular microscope, incorporating fiber-optic and other lighting techniques, was used to document the microscopic features. Color zoning and internal growth structures were analyzed with a horizontal microscope, a specially designed stoneholder, and a mini-goniometer attached to one of the oculars on the microscope, employing the methods described by Schmetzer (1986), Kiefert and Schmetzer (1991), and Smith (1996). Laser Raman microspectrometry was performed using a Renishaw Raman System 2000 equipped with an argon-ion laser. Semi-quantitative to qualitative chemical analyses were taken on both table and pavilion facets by means of energy-dispersive X-ray fluorescence (EDXRF) spectroscopy performed on a Spectrace TN5000 system, using a program specially developed for the analysis of corundum. Infrared spectra in the region between 7000 and 400 cm^{-1} were taken with a Pye-Unicam FTIR spectrometer using a diffuse reflectance unit.

RESULTS

Visual Appearance. When viewed face up with the unaided eye, all samples displayed a saturated red color (again, see figure 1). The color appeared relatively homogeneous, although closer inspection revealed that it was slightly uneven or patchy in some of the samples.

In contrast, when the samples were viewed face down (particularly over a white background, such as a piece of paper), all but two displayed uneven or patchy color distribution that correlated to the facet arrangement of the stones (see, e.g., figure 2).

The three samples that were repolished clearly revealed a saturated red coloration that was confined to a shallow surface-related layer, whereas the main body of the stone beneath this color layer was essentially colorless (figure 3).

Gemological Characteristics. The pleochroism, birefringence, optic character, and specific gravity of all samples were consistent with corundum in general (see, e.g., Webster, 1983; Hurlbut and Kammerling, 1991; Hughes, 1996).



Figure 1. These strongly saturated red stones were marketed as "Diffusion Ruby." However, gemological testing revealed that they are actually the result of a synthetic ruby overgrowth onto colorless to near-colorless natural sapphire. These six samples (0.80–1.12 ct) are part of the group studied in detail for this report. Photo by Maha Tannous.

A few samples displayed typical corundum R.I. readings from the table facet (i.e., $n_o = 1.760\text{--}1.761$, $n_e = 1.768\text{--}1.770$), although the readings were less distinct than normal. Rather unexpectedly, most of the readings revealed an R.I. that was over the lim-

Figure 2. When viewed face down, most of the synthetic-overgrowth corundum samples readily showed uneven coloration between adjacent facets. The degree of visibility, however, was very dependent on the thickness of the overgrowth layer. Photo by Maha Tannous.



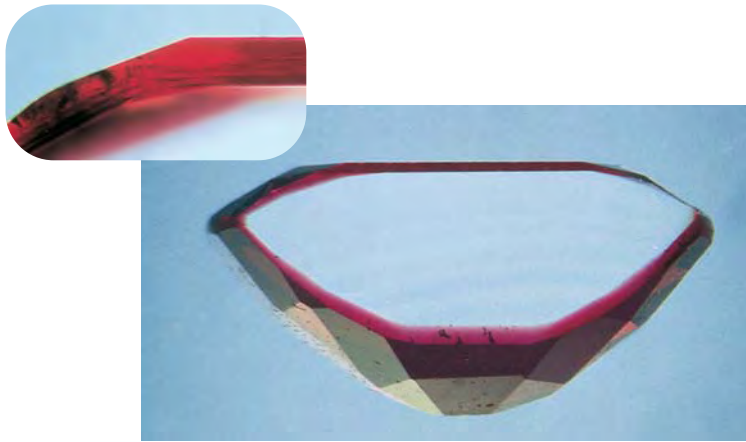


Figure 3. To better observe the overgrowth layer and the core, a 0.86 ct sample was recut and repolished into a 2-mm-thick slice along the center of the length (approximately 6.5 mm). The colorless core of the natural "host" and the deeply saturated red synthetic overgrowth layer are clearly evident. Inset: With higher magnification, the sharp, distinct boundary between the colorless core and the saturated red outer layer is readily seen. Magnified 40 \times .

its (OTL) of a standard refractometer (>1.81). All readings taken on the pavilion facets were OTL. The R.I. of the colorless "core" region in the recut and repolished thin slice revealed normal corundum readings of $n_o=1.760$ and $n_e=1.768$.

The absorption spectra of all samples were typical of ruby, both natural and synthetic (see, e.g., Liddicoat, 1989), and ranged from weak to very strong. In addition, all the samples were inert to faint red when exposed to long-wave UV radiation. One stone also displayed faint orange fluorescent zones that were confined to the interior of the stone. All stones were inert to short-wave UV.

Figure 5. Many indentations or cavities at the surface of these stones extended the full depth of the overgrowth layer, down to but not beyond the boundary with the natural corundum. Typically, the walls of these indentations displayed a stepped morphology consistent with the formation of many small external crystal faces. Magnified 50 \times .

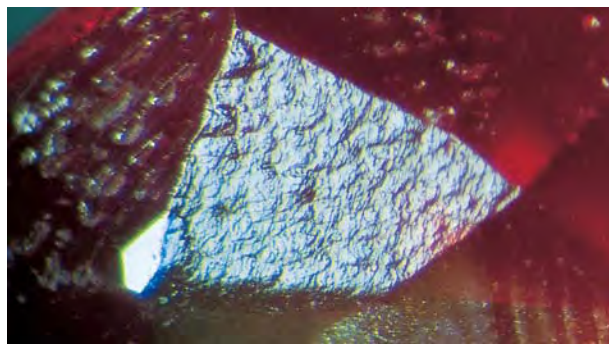


Figure 4. On several of the samples, areas of the original "skin" of the synthetic overgrowth layer remained at the surface. In reflected light, the surface topography of these areas shows characteristics of crystal growth, as opposed to the surface etching that would be expected for true red lattice diffusion-treated corundum. Magnified 28 \times .

Microscopic Features. Surface Features. Several of the samples retained areas of the original surface of the outer layer (see, e.g., figure 4), which had not been removed during repolishing. The contours of these areas were smooth and slightly undulating, as well as stepped with series of small, planar surfaces that resembled the development of multiple crystal faces. Also noted were several indentations or cavities, the walls of which revealed similar stepped planar surfaces (figure 5). These indentations were highly concentrated in some areas; they occasionally extended the full depth of the shallow outer layer, but never into the interior region.

Color Zoning and Internal Growth Features. The patchy color concentrations between adjacent facets

Figure 6. The uneven distribution of color was easily seen when the samples were immersed (here, in methylene iodide) and viewed with a diffused transmitted light source. Photo by Maha Tannous.



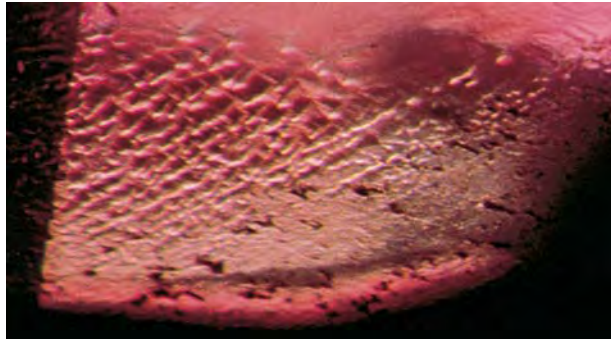


Figure 7. Within the overgrowth layer could be seen a distinctly mottled or roiled texture, which was related to the irregular growth formation. Magnified 38 \times .

seen in some samples with the unaided eye were even more apparent with magnification, especially with a diffused light source (using a standard diffuser plate or even a piece of tissue paper). With immersion (e.g., in methylene iodide) over a diffused light source, all samples clearly displayed uneven color concentrations between adjacent facets and facet edges (see, e.g., figure 6). In the three repolished samples, the demarcation between the saturated red surface-related layer and the colorless zone beneath it was even more dramatic (again, see figure 3).

In all samples, the red coloration halted dramatically at a boundary plane visible just below the surface. The “bleeding” of color between outer and inner regions that is typical of blue and red lattice diffusion-treated corundum (see, e.g., Kane et al., 1990; McClure et al., 1993; Hughes, 1996) was not evident in any of the samples. One sample also revealed a yellow-to-orange color zone confined to one area of its interior.

Other observations made more readily with immersion included irregular “roiled” or striated growth features within the shallow surface layer (figure 7). In contrast, the interiors of the stones showed subtle to prominent planar and angular sequences of internal growth structures composed of the basal pinacoid c {0001}, positive rhombohedron r {10 $\bar{1}$ 1}, and combinations of various di-pyramidal growth planes. These features are typical of natural corundum.

Another distinctive feature visible with immersion—an image reminiscent of a series of steep mountainside contours (figure 8)—was created by the combination of the external surface of the synthetic overgrowth layer, the subsurface of the natural core, and the areas where the boundary plane intercepted the external surface. The author had not previously encountered such a feature in natural, diffusion-treated, or synthetic ruby.

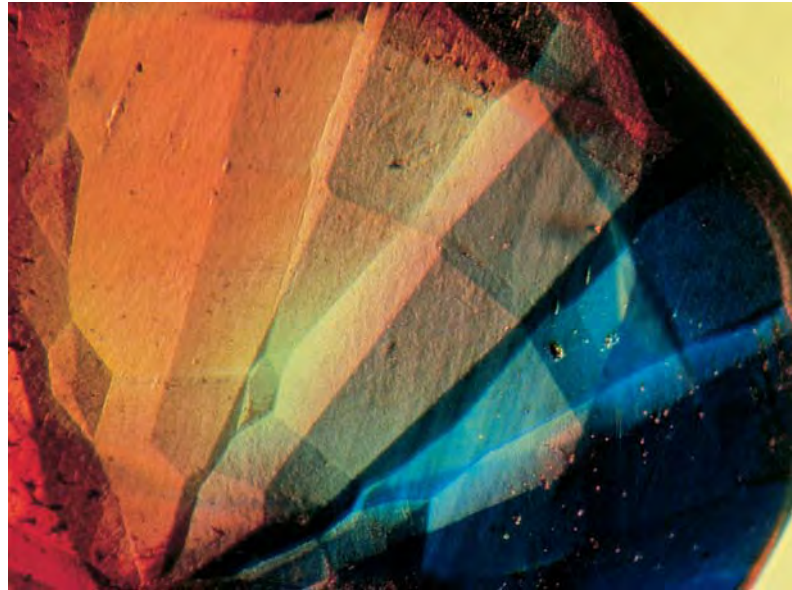


Figure 8. A unique characteristic noted with immersion and transmitted light in all the samples was an image that resembled a series of steep mountainside contours. Magnified 15 \times .

Inclusions. During microscopic examination, it became obvious that there were two different sets of inclusions in each sample, separated by the boundary plane. One set was concentrated along the boundary and within the thin outer layer; the other was present only in the interior of the gem.

The most significant inclusion features occurred at the boundary, which typically was accompanied by a high concentration of unidentified inclusions that were present in generally parallel, linear formations (figure 9). In some areas, these inclusions changed orientation but remained aligned with one

Figure 9. A high concentration of aligned inclusions occurred during the initial deposition of the synthetic overgrowth. As a result, these inclusions clearly demarcated the boundary between the host gemstone and the synthetic overgrowth. Magnified 22 \times .



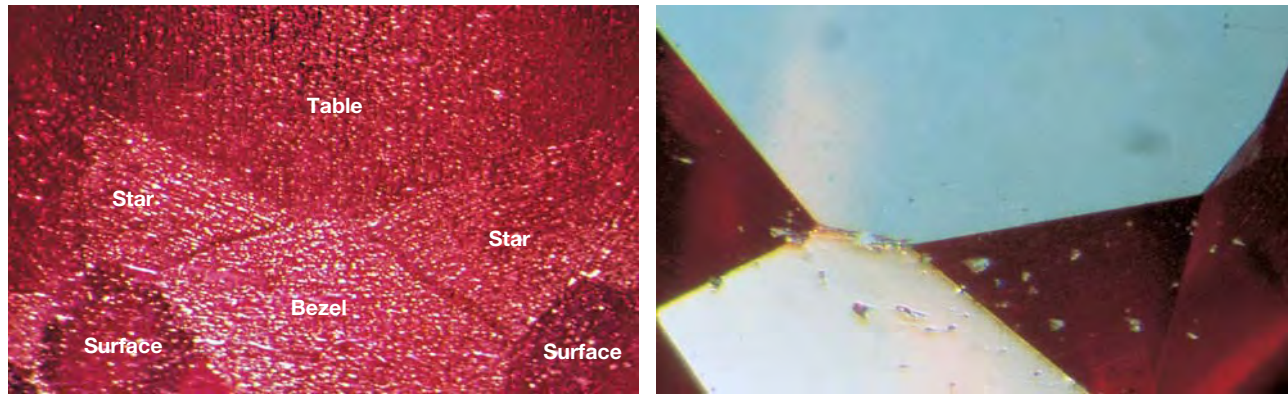


Figure 10. On the left, the table, bezel, and star facet arrangement of the faceted natural corundum core is clearly visible just below the surface of this 0.95 ct sample. Also note the two surface areas devoid of aligned inclusions, where entire portions of the overgrowth layer have been polished away. On the right, this same area viewed with reflected light clearly shows that the external facet arrangement of the synthetic overgrowth layer (i.e., the surface of the stone) does not correspond to that of the natural corundum core. Magnified 32 \times .

another. The various angles created by the abrupt changes in orientation were not consistent within individual samples or between samples in this study; nor did they correlate to angles related to the formation of internal growth structures (see, e.g., Smith, 1996). Furthermore, geometric outlines resembling bezel, star, upper-girdle facets, and pavilion step facets were seen below the surface, where the aligned inclusions at the boundary plane changed directions (figure 10).

As a result of repolishing, the planar boundary did not occur at a uniform depth beneath every facet. In some areas of each sample, the red outer layer was less than 0.1 mm thick, whereas in other areas it was as much as 0.3 mm thick. In several of the samples, this boundary and the associated concentration of inclusions intercepted the surface of the stone (areas where repolishing had completely removed portions of the outer layer).

Turbid bluish white clouds could be seen throughout the outer layer, as well as along or just beneath the boundary, within the host sapphire plane. Sometimes these clouds were homogeneous in texture; other times they were distinctly mottled and uneven. Also observed in the outer layer were numerous pinpoint inclusions (figure 11).

A variety of inclusion features in the interior regions of the samples extended to, but not beyond, the boundary plane (figure 12). In addition, all samples showed evidence of high-temperature thermal alteration. These included altered remnants of rutile needles, platelets, and stringer formations, as well as apparently unaltered needle, platelet, and stringer formations of presumably hematite or ilmenite. Small crystalline inclusions, as well as series of negative crystals, were accompanied by altered and/or

induced stress fractures. Most samples contained naturally occurring healed fractures, which further revealed evidence of thermal alteration.

Raman Analysis. Raman spectra of two repolished stones, taken specifically to analyze only the strongly colored outer layer above the boundary plane and the interior region of the samples, confirmed that in both areas the material was corundum, with Raman peaks located at 750, 577, and 419 cm^{-1} (see, e.g., Hänni et al., 1996; Williams et al., 1997).

Chemical Analysis. EDXRF revealed a significant variability in the chromium (Cr_2O_3) concentrations (from less than 0.01 or “not detected” to 12.8 wt.%) recorded from the table facet as well as from different sides of the pavilion on individual samples and from one sample to another. Analyses taken on facets where the shallow outer layer was present revealed 4.0–12.8 wt.% Cr_2O_3 . A rough general correlation could be made between the thickness of the outer layer and the Cr concentration (i.e., thinner layer, lower relative Cr concentration—thicker layer, higher relative Cr concentration). Chemical analyses taken on the interior regions of the repolished samples, as well as on facets of other samples where the outer layer had been removed by repolishing, did not reveal any detectable Cr. None of the analyses taken on the outer layers detected any sodium or heavy elements such as lead, platinum, tungsten, bismuth, molybdenum, or the like.

Infrared Spectroscopy. All of the spectra revealed the absorption characteristics of corundum between approximately 1500 and 300 cm^{-1} (see, e.g., Smith, 1995). No other absorption bands relating to struc-

tural OH groups or other foreign mineral phases were seen.

DISCUSSION

Raman analysis proved that the outer layer of highly saturated red color was corundum (i.e., ruby). The synthetic origin of this outer layer/overgrowth was determined by the presence of a distinct boundary plane, as well as by the inclusion features that were confined to the boundary and the shallow layer outside this boundary. The inclusion features observed within the interior region of the stones provided clear evidence of the natural origin of the corundum core (see, e.g., Gübelin and Koivula, 1986). The concentration of inclusions along the boundary plane revealing the outlines of crown and pavilion facets confirmed that the natural corundum used as the starting material was faceted.

Synthetic overgrowth on a natural seed is not new to gemology. Probably the best-known commercial product involved the growth of synthetic emerald onto a natural beryl host, first achieved by Lechleitner in 1959 (see, e.g., Gübelin, 1960–61; Bank, 1976; Schmetzer et al., 1981). However, Lechleitner also experimented with the same approach on corundum. For a review of the features noted for those samples, the reader is referred to Schmetzer and Bank (1988). In this well-illustrated article, the authors describe samples where Lechleitner had grown synthetic ruby on top of natural “pale to even colourless corundum seeds. . . .” (p. 97). In many respects, the features described in

that paper are consistent with those observed in the present study. These include the presence of a sharp boundary between the natural corundum “seeds” and the synthetic ruby overgrowth, as well as two types of inclusions (i.e., those of the natural corundum seed and those of the synthetic ruby overgrowth).

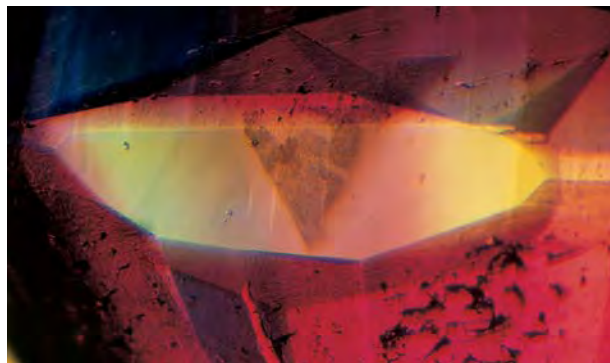
However, there are some differences in the specific inclusion features noted for the synthetic ruby overgrowth. Schmetzer and Bank describe needle-like and doubly refractive inclusions, which were not observed in the present samples. Conversely, their article did not mention the presence of inclusions aligned along the boundary and turbid clouds within the overgrowth layers, which were typical of the present samples. The authors noted similar internal growth structures associated with the natural corundum host, but not the seemingly unique patterns observed with immersion, such as those that resembled a steep mountainside or the roiled appearance. The latter is somewhat similar to the internal growth features seen in hydrothermally grown synthetic rubies (see, e.g., Peretti and Smith, 1993), but closer inspection revealed distinct differences.

Although Schmetzer and Bank did not mention the chromium concentrations of their samples, they did detect molybdenum, which proves that Lechleitner was using a commercial flux method to grow the synthetic ruby layer. Molybdenum or other elements typical of commercial flux-growth

Figure 11. Turbid bluish white clouds confined to the overgrowth layer commonly displayed a distinctly mottled texture. Also note the multitude of pinpoint inclusions that were typically present throughout the overgrowth layer. Magnified 25×.



Figure 12. This 0.80 ct sample was repolished to illustrate clearly how this naturally occurring healed fracture in the core extends up to, but not beyond, the boundary with the synthetic ruby overgrowth. Also note the sharp color demarcation between the essentially colorless natural corundum core and the deeply saturated synthetic ruby overgrowth layer. Magnified 25×.



processes for synthetic rubies were not detected in the present study.

Although the present author was informed by one of the suppliers that the producer insisted these stones were “diffusion treated” and not a synthetic ruby overgrowth (J. Boyles, pers. comm., 1998), there is not sufficient information to determine the source of the overgrowth. It could have been produced by a commercial flux-growth process that used a flux involving elements that could not be detected by EDXRF (such as lithium). The absence

of structurally bonded OH groups in the infrared spectrum precludes production of the synthetic overgrowth layer by any commercial hydrothermal, flame-fusion, Czochralski, or floating-zone synthetic growth method.

Alternatively, the layer could have been produced unintentionally in the course of an attempt at true lattice diffusion treatment that used an aluminum-based flux. Such a flux (containing significant amounts of Cr) is proposed, because the faceted surface of the core natural corundum did not show any evidence of the surface dissolution that would have been needed to supply the alumina necessary for the volume of synthetic ruby that was subsequently grown. Nevertheless, we do know that when heat-treatment techniques are used in combination with chemical additives (fluxes), processes similar to those that take place during the growth of synthetic rubies and/or sapphires may also occur. For example, as part of an ongoing research project into the heat treatment of corundum, the Gübelin Gem Lab heated natural rubies with a commercially available aluminum-silicate flux to try to heal fractures. This experiment resulted in the unexpected growth of a significant amount of synthetic corundum on the surface of the rubies heated with that particular flux. Recently, evidence of the deposition of synthetic materials, including corundum, was detected on the surface of samples of the “new” beryllium lattice diffusion-treated corundum, which also is produced in Thailand (see, e.g., <http://www.agta.org/consumer/gtclab/treatedsapps01.htm> and Gem Trade Lab Notes, this issue, pp. 255–256).

At first glance, the patchy color concentrations of this material are consistent with its representation as “Diffusion Ruby.” In fact, red lattice diffusion-treated corundum (as reported by McClure et al., 1993) and stones with a thin synthetic ruby overgrowth may have several traits and properties in common. These include:

- Shallow color concentration confined to the near-surface
- A patchy or uneven coloration, following the facet arrangement, viewed both with the unaided eye and with magnification over diffused light or, more markedly, with immersion
- OTL refractometer readings (i.e., >1.81)
- Elevated chromium concentrations
- Evidence of high-temperature alteration of inclusions

TABLE 1. Separation of red lattice diffusion-treated corundum from corundum with a synthetic ruby overgrowth.

Synthetic ruby overgrowth	Red lattice diffusion treatment ^a
Inert to short-wave UV radiation	Chalky bluish white to yellowish white short-wave UV fluorescence, confined to the surface
Remnants of the outer “skin” of the overgrowth layer, which reveal traits characteristic of crystal growth	Whitish inclusions along the surface resulting from damage due to the treatment
Indentations at the surface revealing characteristics of crystal morphology; do not extend beyond the boundary	Etch pits and voids at the surface, accompanied by concentrations of diffused color
A boundary plane at or just below the surface	No boundary plane
Two sets of inclusions: (1) in the natural corundum core, and (2) in the synthetic overgrowth	Inclusions typical of natural corundum that may extend from the interior to the surface
A high concentration of inclusions aligned along the boundary plane, often highlighting the facet arrangement of the host gemstone	Nothing similar
Pinpoint inclusions that are confined to a shallow depth and do not extend past the boundary plane	Nothing similar
Bluish white turbidity that is confined to a shallow depth and extends only to the boundary plane or just beneath it	Nothing similar
A shallow red coloration that has a sharp and distinct planar border between the overgrowth layer and the interior of the gemstone	A shallow red coloration that “bleeds” at the edges
Irregular or striated growth structures within the overgrowth layer	Nothing similar
An image of steep mountainside “contours” visible with immersion at the surface/contact plane of the host gemstone with the overgrowth	Nothing similar

^a From McClure et al. (1993).

However, on close inspection, a number of features will readily separate true red lattice diffusion-treated corundum from stones that owe their coloration to a thin overgrowth of synthetic ruby on top of natural corundum seeds (table 1).

Probably the single most diagnostic feature of the synthetic overgrowth is the aligned concentration of inclusions at the contact plane of the natural corundum core and the overgrowth layer. The location, orientation, and visual appearance of these aligned inclusions clearly demonstrates that they formed during the initial deposition of synthetic ruby, along the original polishing directions of the faceted natural "host." Repolishing/faceting of the stones after deposition of the synthetic overgrowth layer typically results in a non-uniform thickness of that layer and even its complete removal in some areas. In all of the samples examined to date, the facet arrangement of the core natural corundum was visible below the surface layer and did not correspond to the facet arrangement at the surface of the overgrowth (again, see figure 10).

The thickness (or absence) of the overgrowth layer had a significant effect on the properties recorded for these samples. On facets where the synthetic overgrowth was no longer present, normal R.I. readings for corundum were recorded. On facets where the overgrowth was very thin (less than approximately 0.1 mm), the edges of the refractive indices were rather "fuzzy," as compared to the "sharp" edges normally observed. The facets with thicker overgrowth layers always displayed OTL R.I. readings. Elevated R.I. readings are consistent with corundum that contains higher than normal "trace element" concentrations (see, e.g., Webster, 1983; Peretti et al., 1995). And when chromium is significantly higher (as noted in red lattice diffusion-treated samples; McClure et. al., 1993), >1.81 readings also have been recorded previously.

Colorless to near-colorless natural sapphires were used as the "seeds" for this treatment, because they typically lack the trace-element concentrations necessary to impart color as a result of heat treatment. It is particularly important that the natural starting material contain low relative concentrations of tita-

nium and iron so the host will not develop a distinct blue coloration during the heating process, thus producing an overall purple coloration once the synthetic ruby overgrowth is added. The orange color concentration in the interior of one sample is attributed to trapped-hole color centers associated with naturally occurring magnesium (Mg^{2+}) that were created during the heating/overgrowth process (see, e.g., Emmett and Douthit, 1993).

CONCLUSIONS

Red lattice diffusion-treated corundum was introduced in the early 1990s, so this author was not surprised when gems were being offered as "Diffusion Ruby" by a variety of gem dealers over the past few years. Indeed, there are a number of similarities between true red lattice diffusion-treated corundum and the samples offered as "Diffusion Ruby." These consist of patchy color concentrations from one facet to the next, high chromium concentrations, and OTL refractive index readings. However, these synthetic ruby overgrowths are readily distinguished by several traits, which include the presence of a boundary plane at the interface of the natural corundum core and the synthetic ruby overgrowth layer located just below (or sometimes reaching) the surface of the stone, as well as different inclusion features in the synthetic overgrowth layer as compared to the natural corundum seed. In addition, the synthetic overgrowth is inert to short-wave UV radiation.

Although synthetic ruby overgrowths on natural corundum were produced experimentally some 20 years ago, the description of colorless to near-colorless natural sapphires with a thin layer of synthetic ruby overgrowth seems particularly timely today when one considers the controversy surrounding the deposition of synthetic corundum in the course of the new beryllium lattice-diffusion treatment of corundum. As treatment techniques that incorporate fluxes in conjunction with high temperatures continue to develop and evolve, the distinction between natural, treated, and synthetic corundum may become increasingly difficult.

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Gem Trade LAB NOTES



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BROMELLITE

Occasionally we are fortunate to receive for identification faceted examples of minerals that are seldom if ever seen fashioned as gemstones. The West Coast laboratory had such an opportunity when three transparent colorless stones weighing 0.68, 1.92, and 2.80 ct (figure 1) were submitted by Dunil Palitha Gunasekera of Ratnapura, Sri Lanka. He suspected these stones to be johachidolite, a rare borate mineral first described as a cut gem by R. Harding et al. in 1999 (*Journal of Gemmology*, Vol. 26, No. 5, pp. 324–329).

However, the results of gemological testing did not match the properties given for the johachidolite described in the above article (R.I.=1.717–1.724, S.G.=3.45). Instead, testing showed R.I.'s of 1.718–1.732 and an S.G. of 3.01–3.03. The stones were inert to long-wave ultraviolet (UV) radiation, showed only a very weak yellow reaction to short-wave UV, and no absorption bands were visible in the desk-model spectroscope. These properties did not match any gem material with which we were familiar.

The mystery deepened when energy-dispersive X-ray fluorescence



Figure 2. This 5.84 ct synthetic BeO crystal was grown experimentally in Russia.

Figure 1. These three transparent colorless stones (0.68, 1.92, and 2.80 ct) are believed to be the first reported faceted specimens of the mineral bromellite.



(EDXRF) analysis of the 2.80 ct sample failed to detect any elements at all. While our EDXRF spectrometers are sensitive only to the elements sodium and higher on the periodic table, this was the first time we could recall that the instrument did not detect *any* elements within a crystalline sample. GIA research gemologist Shane Elen, on hearing of these results and having just read the

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Figure 3. Large, white, irregular flux inclusions were present in both samples of synthetic bromellite examined for this study. Magnified 40x.



Figure 4. All of the faceted bromellites revealed groups of transparent colorless irregular crystals similar to that shown here in the 0.68 ct sample. Magnified 40x.



Figure 5. Also present in all of the faceted bromellites were several transparent rounded yellow crystals surrounded by haloes. Magnified 40x.

chapter on synthetic gemstones in J. E. Arem's *Color Encyclopedia of Gemstones* (2nd ed., 1987, Van Nostrand Reinhold, New York), suggested BeO as a possible chemical makeup. Arem mentions that colorless BeO crystals, with the mineral name bromellite, have been grown synthetically.

We then turned to an X-ray powder diffraction database, limiting our search to inorganic minerals with an S.G. of 2.92–3.12 and eliminating many of the elements detectable by EDXRF. The search provided a list of three possibilities (with formulas as indicated in the database): sidwillite [MoO₃·2H₂O], hydroxylbastnäsite [Nd(CO₃)(OH)], and bromellite [BeO]. We eliminated the first two minerals because neither Mo nor Nd was detected in the chemical analysis, and the R.I.'s of both are distinctly different from those we had recorded. Published values for bromellite, however, almost exactly fit the R.I. and S.G. of the samples in question. The identification was confirmed when Raman spectra of the samples yielded a good match for bromellite from the Renishaw Raman database.

Since none of us had ever heard of bromellite being fashioned as a gemstone, and a search of the gemological literature did not reveal any mention of this mineral being cut

and polished, we next addressed the question of the natural or synthetic origin of these three samples. Synthetic bromellite has been grown for nearly four decades (see, e.g., H. W. Newkirk and D. K. Smith, "Crystal growth, morphology and twinning of synthetic macrocrystals and microcrystals of bromellite," *Acta Crystallographica*, Vol. 16, Pt. 13, 1963, p. 142). One of the authors (SFM) located two crystals of BeO that were represented as having been grown experimentally in Russia. The Raman spectra obtained on one of the crystals (figure 2) matched the spectra of the faceted stones. However, these crystals still had remnants of the wires from which they were suspended in their growth environment, as well as large, white, irregular inclusions that were probably flux trapped during growth (figure 3). These inclusions should be easily recognizable as proof of synthetic origin in a faceted stone.

In contrast, the internal features of the three stones submitted to the lab included planes of liquid inclusions, transparent colorless irregular crystals (figure 4), transparent yellow rounded crystals (figure 5), and numerous thin needles (figure 6). The nature of these inclusions, plus the obvious difference from those seen in the known synthetics, was sufficient to prove the natural origin

of these bromellites. According to R. V. Gaines et al. (*Dana's New Mineralogy*, 8th ed., John Wiley & Sons, New York, 1997, p. 211), bromellite has been recovered from skarns in Sweden and Texas, from the emerald mines in the Ural Mountains of Russia, and from unspecified rocks in Norway.

We believe these three stones are the first reported examples of faceted gem-quality bromellite. For future reference, table 1 lists the properties of this new gem material.

SFM and Sam Muhlmeister

Figure 6. Numerous thin needles, which did not display any particular orientation within the stones, were seen in all the faceted bromellites and helped confirm their origin as natural. Magnified 29x.



TABLE 1. Properties of bromellite.

Property	Characteristic
Color	White ^a or colorless
Luster	Vitreous ^a
Hardness	9 ^a
Cleavage	{10 $\bar{1}$ 0} perfect; {0001} good ^a
Refractive indices	$n_o=1.718$, $n_e=1.732$
Birefringence	0.014
Crystal system	Hexagonal ^a
Optic character	Uniaxial positive
UV fluorescence	
Long-wave	Inert ^b
Short-wave	Inert to weak yellow ^b
Absorption spectrum	No features seen
Specific gravity	3.01–3.03
Inclusions	Planes of liquid inclusions, transparent colorless irregular crystals, transparent yellow rounded crystals, numerous thin needles

^aFrom Gaines et al. (1997).

^bFor bromellite from Norway, Gaines et al. (1997) reported white fluorescence to short-wave UV, whereas yellowish white fluorescence to both short- and long-wave UV was reported by A. O. Larsen et al. ("Bromellite from syenite pegmatite, southern Oslo region, Norway," *Canadian Mineralogist*, Vol. 25, No. 3, 1987, pp. 425–428).

CHAROITE Inclusions In a Quartz-Feldspar Rock

In the Winter 2001 Lab Notes section (p. 318), we reported on the examination of an interesting 292.14 ct cabochon of charoite with tinaksite that was submitted to the West Coast laboratory by gemologist Leon M. Agee of Agee Lapidary in Deer Park, Washington. More recently, Mr. Agee sent another "charoite" cabochon for examination, which turned out to be just as interesting as the previous gem. This new cabochon weighed 73.55 ct and measured 39.12 × 27.56 × 7.20 mm (figure 7).

Although for the most part the cabochon resembled charoite in appearance, the gemological properties were consistent with quartz, not charoite. Examination with magnification and testing with laser Raman microspectrometry revealed that the cabochon consisted primarily of a

mixture of transparent to semitransparent near-colorless quartz and, to a much lesser extent, feldspar. Within this host matrix, numerous lavender-colored inclusions were identified as charoite by Raman analysis. These inclusions primarily took the form of dense curved and twisted bundles of fibers and fine sprays of needles, but some individual fibers were also noted. Where the inclusions were particularly dense, the charoite gave the host quartz/feldspar a pleasing lavender color. Where the inclusions were finely disseminated, they made the host slightly translucent but did not add any appreciable color. This is the first time we have encountered charoite as a recognizable inclusion in another gem material.

JIK and Maha Tannous

DIAMOND

Altered vs. Natural Inclusions in Fancy-Color Diamonds

Characterizing gemological features has always been critical in determining the origin of color in a diamond. With the increased use of high pres-

sure/high temperature (HPHT) technology to change the color of diamond, this endeavor has become even more important. The intense heat and pressure generated by this treatment may alter internal characteristics, thus leaving clues for the gemologist. Yet interpretation of these clues can be very challenging, as evidenced by two diamonds recently submitted to the East Coast laboratory for origin-of-color reports.

The 3.38 ct Fancy Intense blue marquise and 1.20 ct Fancy Vivid orange-yellow pear shape exhibited very similar inclusions that looked suspiciously like those often found in HPHT-annealed stones (see, e.g., T. M. Moses et al., "Observations on GE-processed diamonds: A photographic record," Fall 1999 *Gems & Gemology*, pp. 14–22; and I. M. Reinitz et al., "Identification of HPHT-treated yellow to green diamonds," Summer 2000 *Gems & Gemology*, pp. 128–137). In figure 8, the blue diamond displays a large, flat, apparently graphitized inclusion surrounded by a colorless halo. Similarly, in figure 9, the yellow diamond also has a large, flat inclusion

Figure 7. Consisting primarily of quartz and, to a much lesser extent, feldspar, this 73.55 ct cabochon was decorated internally with fibrous bundles and fine sprays of charoite.





Figure 8. The tension halo in this 3.38 ct blue diamond appears similar to inclusions seen in HPHT-annealed diamonds. However, the smooth, shiny appearance of the halo suggests that the color in this diamond is natural, as was confirmed by spectroscopy. Magnified 45 \times .



Figure 9. The tension halo in this 1.20 ct orange-yellow diamond appears similar to the one in figure 8. In this case, however, the sugary texture and undulating nature of the halo suggests that this diamond has been exposed to an HPHT process, which was confirmed by spectroscopic analysis. Magnified 45 \times .

that appears to be graphitized, with a colorless halo surrounding it.

After further examination, we noted subtle but significant differences between these two inclusions and their associated tension halos. The halo in the blue diamond was quite flat with little or no relief. The halo in the yellow diamond appeared to undulate as it went around the dark center. Also, the surface of the halo in the blue diamond was very shiny in reflected light, whereas the surface of its counterpart in the yellow diamond revealed a less reflective, sugary appearance.

Black inclusions are relatively common in natural-color type IIb blue diamonds (see J. M. King et al., "Characterizing natural-color type IIb blue diamonds," *Winter 1998 Gems & Gemology*, pp. 246–268). They are less common in natural-color yellow diamonds, but they are not unknown. Tension haloes can form naturally around inclusions in any diamond.

The conditions of HPHT annealing also can create tension haloes around existing inclusions while stimulating graphite formation along the crystal faces of those inclusions. The result may be a large, flat inclusion with a dark center, which is surrounded by a transparent/translucent halo.

However, there are subtle differences in tension haloes produced naturally and those resulting from HPHT processing. This led us to suspect that the orange-yellow diamond had in fact been color enhanced by HPHT annealing, while the blue one had not. Because the HPHT process subjects a diamond to intense heat and pressure for a relatively short period of time, the damage it often causes to existing features may be severe. From our experience, the sugary texture and undulating nature of the tension halo in the orange-yellow pear shape suggested that this diamond was subjected to a rapid change in heat and pressure, whereas the smooth, shiny appearance of the halo in the blue diamond indicated that it was caused by a slower, natural process. Spectroscopic analysis confirmed the observations we had made with magnification: The blue diamond had not been HPHT annealed, and the orange-yellow diamond had. These examples further validate the need for both careful gemological observations and advanced analytical testing to arrive at a correct origin-of-color determination.

Thomas Gelb and
Matthew Hall

With "Compact Disc" Inclusion

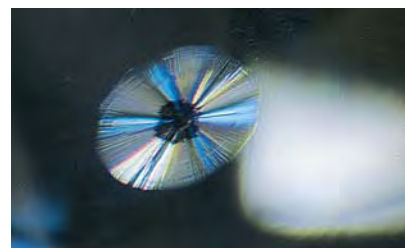
During the process of clarity grading a diamond, graders will occasionally come across inclusions that are reminiscent of some familiar object that adds interest to the diamond even if it also lowers the clarity grade of the host. Such was the case when a near-colorless 0.97 ct round brilliant was submitted to the West Coast laboratory for a diamond grading report.

The dark portion of the inclusion observed in this diamond was too deep to be identified by Raman analysis. Through the microscope, however, and in darkfield illumination, the inclusion appeared to be composed of an opaque dark gray to black graphite and/or sulfide center that was surrounded by an almost perfectly circular cleavage disk.

When the inclusion was examined at a slight angle to its plane with a fiber-optic illuminator, the cleavage disk took on a reflective, silvery appearance, with what looked like numerous fine lines arranged in a relatively uniform pattern around the dark center. These grooves appeared to be minute steps in the primary cleavage plane. They were probably extensions of the other three directions of octahedral cleavage that is typical of diamond.

When the fiber-optic illuminator was placed in one specific position, as shown in figure 10, the light scattered

Figure 10. Extending from a dark inclusion in a near-colorless diamond, this cleavage disk takes on the appearance of a compact disc when it is illuminated with a fiber-optic light. Magnified 20 \times .



and reflected by the grooves on the cleavage disk formed a distinct radial pattern, with the “flares” varying from silvery white to a slightly grayish blue. To those who viewed the unusual feature, this created the illusion of light reflecting from a compact disc.

JIK and Maha Tannous

HEMIMORPHITE, A Rarely Encountered Gem Material

At first look, the medium-tone, intensely colored greenish blue oval cabochon shown in figure 11 reminded us of high-quality turquoise or possibly chalcedony. The principal refractive indices, measured on the base of the 9.80 ct cabochon, were approximately 1.613–1.635. These quickly ruled out chalcedony, but not turquoise. However, the specific gravity (determined hydrostatically) was approximately 3.45, significantly higher than turquoise.

The cabochon was inert to both long- and short-wave UV fluorescence, and no absorption lines were visible with a desk-model spectroscope. The combination of properties indicated that the cabochon might be hemimorphite [$Zn_4Si_2O_7(OH)_2 \cdot H_2O$]. To confirm this identification, we turned to the advanced techniques of

Figure 11. This 9.80 ct oval cabochon (12.90 × 11.00 × 7.50 mm) was identified as hemimorphite, which is seen only rarely as a fashioned gem.



laser Raman microspectrometry and qualitative chemical analysis using EDXRF spectrometry. With Raman analysis, we observed a strong peak at 932 cm^{-1} , a moderate peak at 682 cm^{-1} , and relatively weak peaks at 333 , 404 , and 455 cm^{-1} ; this spectrum matched well that of our reference sample of hemimorphite. As a further confirmation, EDXRF analysis showed silicon and zinc in high concentrations (along with lower amounts of copper, sodium, and lead). Hemimorphite is a common mineral in the oxidized zone of zinc-bearing mineral deposits. However, we have encountered gems fashioned from hemimorphite only rarely in the laboratory.

For the most part, these observations are consistent with those reported for hemimorphite in the Spring 1998 Lab Notes section (pp. 44–45). Unlike the hemimorphite cabochon reported by R. T. Liddicoat in the Winter 1971–72 Lab section (pp. 383–384), the current cabochon did not show distinctive agate-like banding and it had a more fibrous structure, similar to the cabochon and rough sample reported in 1998.

TM and Wuyi Wang

SAPPHIRE Bulk or Lattice Diffusion Treated

Over the last several months, there has been extensive discussion and research related to the color-enhanced yellow and orange-to-orangy pink sapphires that have been treated mainly in Thailand. The cause of color in these stones has been a major focus of the investigation.

A few key characteristics have been observed in many of the samples examined to date, both by GIA and by other laboratories throughout the world. The first is that the yellow-to-orange color produced by this treatment generally does not penetrate completely through the stone, but is confined to varying depths relative to the outline of the original facets. The second, observed in a smaller number



Figure 12. When immersed in methylene iodide, this nearly 20 ct sapphire shows an orangy yellow layer of color following the outline of the facets, which indicates that it was subjected to a bulk-diffusion process.

of cases, is that there has been recrystallization or new crystal growth on the surface or just below the surface. The third characteristic, observed in samples that have been sectioned and analyzed by sophisticated techniques, is the presence of beryllium in higher concentrations near the surface, or corresponding to the depth of the treated color layer.

A large stone submitted for an identification report in the East Coast laboratory demonstrated how these characteristics could be used to identify this new treatment, which scientifically is referred to as bulk or lattice diffusion. The orangy yellow cut-cornered rectangular mixed cut measured $14.85 \times 12.61 \times 10.71\text{ mm}$ and weighed almost 20 ct. The gemological properties recorded were consistent with sapphire. Examination with a desk-model spectroscope did not reveal any sharp absorption features. However, the stone fluoresced weak orange to long-wave UV radiation, and a moderately chalky but very weak patchy yellow to short-wave UV, which is consistent with heat treatment. Preliminary inspection of this exceptionally clean stone with magnification revealed only a few small chips around the girdle and no diagnostic inclusions to indicate if

the stone was natural or synthetic. However, when the stone was examined while immersed in methylene iodide, a clear demarcation could be seen between a near-colorless core and an orangy yellow zone that followed the outline of the faceted sapphire (figure 12). This was the feature that indicated the sapphire had been subjected to a bulk-diffusion process.

From dozens of past (destructive) chemical analyses, we have confirmed the presence of beryllium in the yellow-to-orange color layer of the bulk diffusion-treated sapphires. Previously, beryllium alone was not known to act as a chromophore; it was believed to be interacting with elements/defects intrinsic to the sapphire to produce the yellow-to-orange color. However, Dr. John Emmett of Crystal Chemistry in Brush Prairie, Washington, reports that recent experiments have demonstrated that beryllium, diffused into the stone in an oxygen atmosphere, can in fact cause color on its own (see <http://www.agta.org/consumer/gtclab/treatedsapps04.htm>).

Although we found compelling evidence that this sapphire had been subjected to a bulk-diffusion process, we still had to prove its origin—natural or synthetic. The absence of Plato lines suggested it was not a melt-process synthetic. Observation of the stone with magnification in diffused illumination revealed a weak straight, parallel growth structure under the table, which is consistent with natural sapphire. Chemical analysis using EDXRF showed, as expected, large amounts of Al with lesser amounts of Fe and Ti and a significant quantity of Ga. The relatively high amounts of gallium and titanium are also indicative of natural origin. *TM*

Bulk Diffusion–Treated Sapphire with Synthetic Overgrowth

Not all of the discussion concerning bulk diffusion of yellow coloration into sapphire has revolved around the source of color. At the extreme tem-

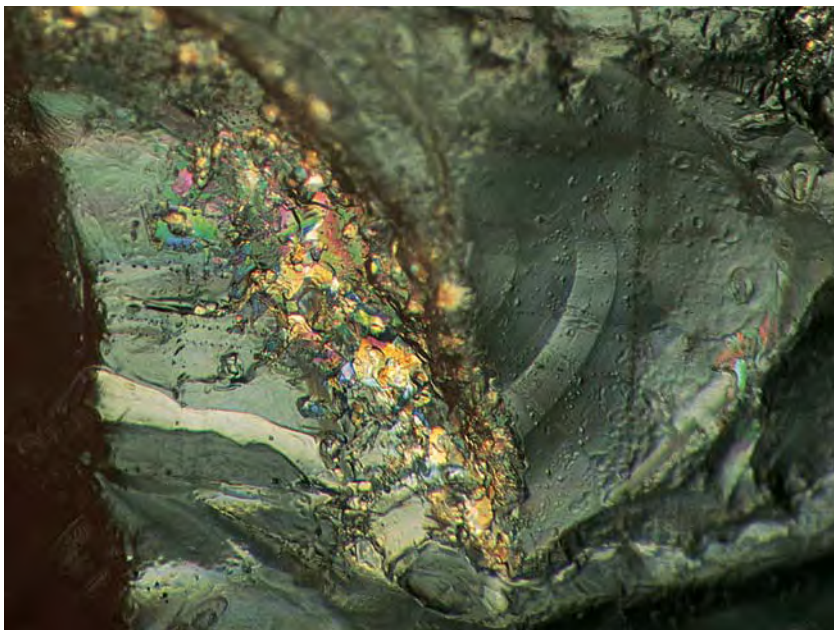


Figure 13. Much of the synthetic corundum growth on the surface of bulk-diffused sapphires is in the form of randomly oriented clusters of crystals, here seen with polarized light. Magnified 20 \times .

peratures required for this treatment, many other changes can take place. One of these is the partial dissolution of the corundum in the crucible (and potentially of the walls of the alumina crucible itself) through contact with fluxes, which can create an environment where synthetic corundum grows on the surface of stones on cooling. During our research on this new treatment, we have seen many examples of corundum “re-deposition” on treated rough and preformed samples, often as groups of minute flat hexagonal platelets. Most of this synthetic corundum is removed when the stones are finished, but we have seen a number of examples—most commonly the treated yellow sapphires—where some of this material was left on the polished stone. Ken Scarratt, of the AGTA Gemological Testing Center, first published his observations on this phenomenon April 19, 2002, on the AGTA Web site (<http://www.agta.org>).

The examples we have seen of synthetic growth on bulk-diffused sapphires have been quite different from

past cases where the synthetic overgrowth has been intentional, such as with Lechleitner synthetic overgrowth on beryl or corundum. In those gem materials, the crystallographic orientation of the overgrowth has been consistent with the orientation of the base material. Synthetic corundum growth on the bulk-diffused sapphires is entirely random in orientation and tends to form clusters of tiny crystals (figure 13). After the stones are polished, this random orientation manifests itself in two ways that make identification of the presence of synthetic material relatively easy.

The first of these is the appearance of the overgrowth in a microscope. With darkfield illumination, these areas look roiled, somewhat like areas of graining, although they are much more isolated than one would expect for natural graining. With transmitted light, however, it is possible to see the edges of many of the individual crystals within this roiled zone (figure 14, left).

The second manifestation is the reaction of the areas of overgrowth to

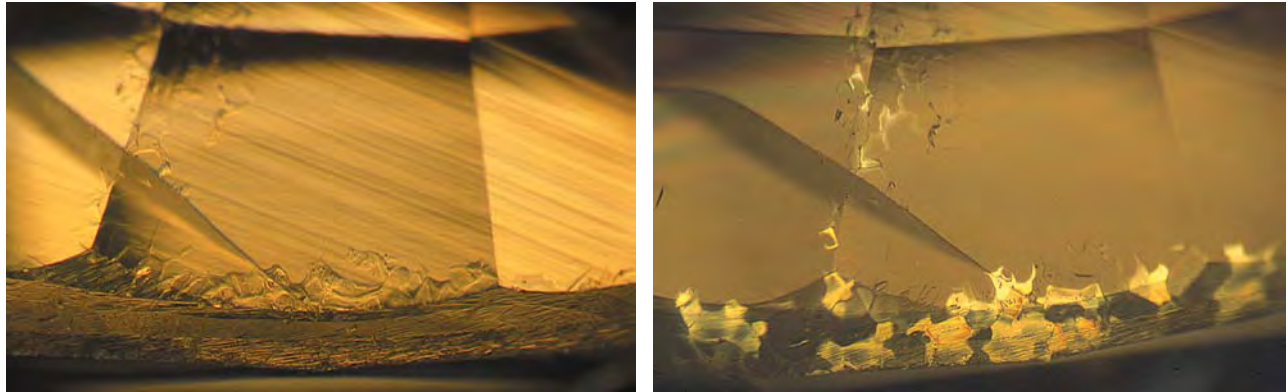


Figure 14. On finished stones, the synthetic corundum growth may show up as roiled areas, with some crystal faces becoming visible in transmitted light (left). When viewed in cross-polarized light (right), the individual crystals of synthetic corundum may become visible as bright areas against a dark background due to differences in their orientation. Both images magnified 40 \times .

cross-polarized light. Because the synthetic crystals are randomly oriented, their directions of extinction should be different from one another, as well as from the host material. With proper orientation (which may require changing the position of the Polaroid plates or the stone), and with the host stone in the dark position, many of the synthetic crystals will be in their light position, which can be seen easily in the microscope (figure 14, right).

To help meet this identification challenge, gemologists must be aware of the possible presence of a synthetic overgrowth and know what it looks like. However, with increasing trade awareness of the overgrowth, the cutters of these stones will probably make every effort to remove all the synthetic material after treatment.

SFM

Synthetic Sapphire Treated by “Traditional” Bulk Diffusion with Transition Elements

Coincidentally, only a few days after the West Coast lab received the orangy yellow bulk-diffused sapphire described above, a client submitted the earring shown in figure 15 for an identification report. Routine gemological testing indicated that the center stone was a sapphire. Like the

orangy yellow sapphire, however, this one was free of any readily apparent inclusions—even with high magnification. It revealed only “wear” marks—small chips and abrasions. It did not show any absorption features with a desk-model spectroscope. There was no visible

Figure 15. The 8.00 \times 6.20 \times 3.80 mm blue stone in the center of this yellow-metal cluster earring set with “old cut” diamonds proved to be a bulk-diffused synthetic sapphire.



reaction to long-wave UV radiation, and the reaction to short-wave UV was a moderately strong chalky yellow or white. This type of short-wave reaction in a sapphire suggests that it has been heat treated or, in the case of a blue sapphire, that it may be synthetic.

Figure 16. As seen with immersion and the earring viewed from the back, the shallow and patchy blue coloration, plus the “outlining” of the facet junctions, serves as proof that the blue color in the synthetic sapphire was produced by bulk diffusion.



When the earring was immersed in methylene iodide, the true identity of the blue stone became clear. The patchy, shallow blue coloration and the concentration of color along facet junctions (or “outlining”; see figure 16) indicated that this stone owed its blue color to a diffusion (now referred to as “bulk diffusion”) process. (For a review of these characteristics, see R. E. Kane et al., “The identification of blue diffusion-treated sapphires,” Summer 1990 *Gems & Gemology*, pp. 115–133.) As the stone was moved and inspected in several positions, we observed an even more interesting feature: Subtle curved blue color banding extended across its width. This confirmed that it was a bulk-diffused synthetic sapphire. The pale blue of the curved banding suggests that this was the color of the starting material.

The process of bulk diffusion is not new; in fact, patents for this procedure (held by Union Carbide) date back to the mid-1970s. Typically, the blue color in such treated sapphires is created by the diffusion of titanium. As noted in the earlier entries, however, we currently are seeing the diffusion of new, light elements into the crystal lattice of corundum. Depending on the elements diffused, the chemistry of the host, and several other variables, the resulting color and properties of the treated corundum may vary widely. This is creating a significant challenge for the corundum market.

Given the identification of the center stone, we were surprised to see that the surrounding diamonds were fashioned in Old European, older Swiss, and single cuts, which are indicative of a period jewelry piece. Although we can never be certain that such a piece of jewelry is an original period piece or a modern reproduction, it added to the intrigue of the identification. If it was an original period piece, the setting obviously would predate the availability of bulk-diffused corundum. This makes one wonder what center stone may have been set in the earring originally or even what kind of stone is in the

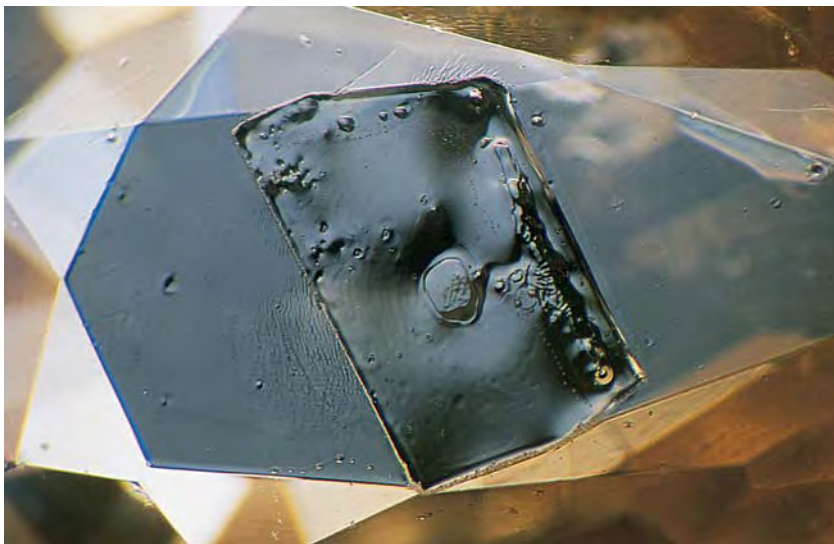


Figure 17. It is readily apparent that no effort was made to remove the surface evidence of high-temperature heat treatment from this 0.95 ct yellow sapphire. Shadowed fiber-optic illumination brings out even small details on the badly damaged table facet. Magnified 10×.

other earring (which was not submitted for identification). TM

Sapphire with Surface Evidence of Heat Treatment

The West Coast laboratory recently had the opportunity to study an interesting heat-treated stone that was purchased in Bangkok from a parcel of commercial sapphires by Lab Notes co-editor Tom Moses. As determined by standard gem identification techniques, the 0.95 ct light yellow pear-shaped mixed cut ($8.34 \times 5.29 \times 2.77$ mm) was a natural sapphire.

Examination with a gemological microscope and a fiber-optic illuminator revealed small, light-scattering particles in distinct angular formation within the stone. The facets were covered with numerous solidified droplets of a transparent material that had a Mohs hardness of approximately 6 and appeared to be amorphous. The table facet in particular revealed obvious surface evidence of high-temperature treatment. As shown in figure 17, flow lines and ridges in the surface layer on the

table were clearly visible with shadowed fiber-optic illumination. Laser Raman microspectrometry confirmed that the host was a sapphire and the thick, amorphous-looking patches and droplets of residue were a glass. The pattern formed by the glass residue suggests that the table of this sapphire was in contact with another surface during treatment.

Identification of heat treatment in this instance was made relatively easy by the complete lack of re-polishing of the sapphire. Although such obvious evidence is rarely encountered, since most heat-treated sapphires are polished after treatment, occasionally remnants of the surface layer will remain on unpolished areas of the stone and aid in the identification.

JIK and Maha Tannous

PHOTO CREDITS

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DIAMONDS

Australia's Ellendale diamond mine opens. On June 24, 2002, the Kimberley Diamond Company (KDC) started production on its Ellendale 9 lamproite pipe. Ellendale is

Figure 1. The Ellendale mine in Western Australia opened in June 2002. Here, an excavator is used to load overburden into a truck from the first mining bench at the Ellendale 9 lamproite pipe. Photo courtesy of Kimberley Diamond Co.



Australia's third active diamond mine; Argyle and Merlin, opened in 1983 and 1999, respectively, are currently operated by Rio Tinto. The Ellendale field encompasses at least 60 lamproite pipes; more than a third of these are on property leased by KDC. The mine (figure 1) is located on a flat, sandy plain along the southwestern periphery of Western Australia's Kimberley region, 140 km (87 miles) east of Derby. The lamproites erupted only ~20 million years ago, which makes them the youngest commercially diamondiferous pipes known (see A. L. Jaques et al., "The age of the diamond bearing pipes and associated leucite lamproites of the West Kimberley region, Western Australia," *BMR Journal of Geology and Geophysics*, Vol. 9, No. 1, 1984, pp. 1-7).

A well-furnished camp built on-site currently houses 80 people involved in the mining (by open pit) and processing

Figure 2. These gem-quality diamond crystals (approximately 0.3-0.5 ct) were mined from the Ellendale 9 pipe. Note the characteristic rounded shape of the crystals. Photo courtesy of Kimberley Diamond Co.



of the ore. The ore grade from the first two months of production is 15 carats per 100 tonnes. A gem-quality diamond of 7.64 ct was found in the first two weeks of production, and in mid-September an 11.4 ct gem was recovered. Gem-quality diamonds weighing 6.9, 7.9, 8.0, and 9.5 ct were found during the 2000/2001 evaluation stage, which indicates that this mine will produce many 5+ ct stones.

Estimates call for the production of 60,000 carats in the first full year of production (July 1, 2002 to June 30, 2003). The first sale, in June 2002, of 4,552 carats recovered during exploration and evaluation generated US\$99/ct. Most of these diamonds, which were sold to David Lapa of Overseas Diamonds in Antwerp, derived from Ellendale pipe 4, which has a higher grade but lower quality than pipe 9. The latest sale (on August 30, 2002) to the same buyer of 4,320 carats from the first mine production of pipe 9 (see, e.g., figure 2) had an average value of US\$133/ct. These results confirm and slightly exceed estimates made in the mining feasibility study by Snowden Mining Associates of Perth. Snowden's study projected two stages of production that would sustain a mining operation of 4–5 million tonnes (yielding 400,000 to 500,000 carats) per year for 10 years.

KDC purchased the Ellendale prospect from Rio Tinto for Aus\$23.25 million in October 2001 after a protracted legal action. A payment of Aus\$2 million was made when the purchasing agreement was signed, and the remainder is to be paid in four installments over three years. Feasibility studies have shown that these payments are well within the economic parameters of the mining operation. After three years the mine should be virtually debt-free.

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COLORED STONES AND ORGANIC MATERIALS

Aquamarine and spessartine from Tanzania. In April 2002, Dr. Horst Krupp (Fire Gems, La Costa, California) showed the *G&G* editors some rough and cut gems that were representative of new production from Tanzania.

An eluvial deposit in the Songea area has produced attractive crystals of aquamarine within the past year. Dr.

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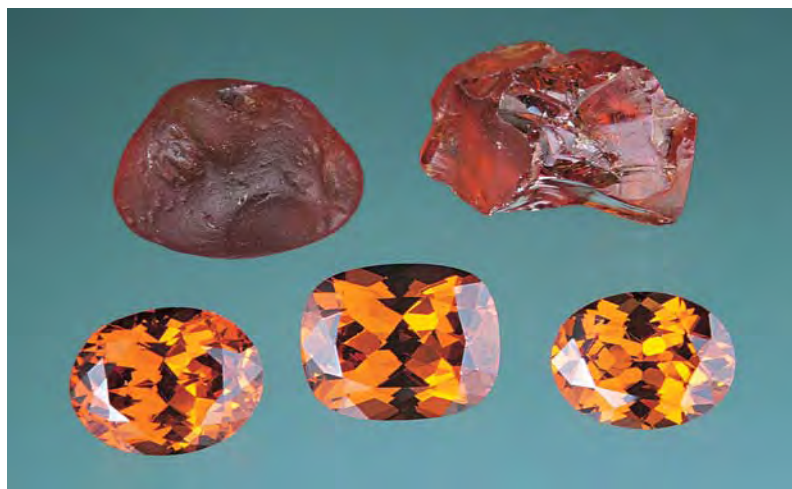


Figure 3. Songea, Tanzania, is the source of these unheated beryl crystals (over 80 grams) and this heated cut aquamarine (32 ct). Courtesy of Horst Krupp; photo by Maha Tannous.

Krupp estimated that 1,000 kg of rough has been recovered, in a range of colors (figure 3); most was sent to Germany for cutting. Crystals up to 800 g have been found, yielding faceted stones as large as 200 ct. The rough typically does not have any eye-visible inclusions, and the vast majority of material is heated to remove the green color component. Reportedly, the deposit is now worked out.

In central Tanzania, mining for spessartine in the Iringa region has accelerated recently. Although production remains sporadic, these recent activities have yielded several kilograms of rough, in sizes up to 25 grams. As can be seen in figure 4, the material shows a rather even consistency of color.

Figure 4. These spessartines (approximately 6–8 ct faceted) were recently mined in central Tanzania. Courtesy of Horst Krupp; photo by Maha Tannous.



Brown beryl from Mozambique. At the Tucson gem show last February, Intergeoresource of Sofia, Bulgaria, offered "black beryl" from the Conco mine in the famous Alto Ligonha pegmatite region of Mozambique. The dark brown, tumble-polished pebbles ranged from <1 ct to almost 10 ct; this contributor obtained two samples for examination and determination of the source of the unusual color.

When viewed with 10× magnification, the material was seen to consist of very light blue aquamarine with black inclusions that lay in planes perpendicular to the optic axis and were surrounded by brown "clouds" of color (figure 5). At 40× magnification, the inclusions appeared to be typical skeletal ilmenites, as well as ilmenite needles oriented in three directions at 120° from one another. Although too small to analyze by laser Raman microspectrometry, skeletal ilmenite inclusions are well known in beryl (see, e.g., E. J. Gübelin and J. I. Koivula, *Photoatlas of Inclusions in Gemstones*, ABC Edition, Zurich, Switzerland, 1986, p. 240), and have been documented together with rutile needles in a brown beryl from Brazil showing asterism (W. F. Eppler, "Notes on asterism. . .," *Journal of Gemmology*, Vol. 6, No. 5, 1958, pp. 195–212).

The darkest part of one sample showed a schiller effect due to these oriented inclusions, but no asterism. When viewed perpendicular to the optic axis, the beryl appeared strongly color zoned, with numerous extremely thin, very dark brown lamellae in an otherwise light blue background (again, see figure 5). These lamellae were correlated to the planar orientation of the skeletal ilmenites and associated brown halos. When the samples were tilted and observed with a rotating polarizer, the brown color showed strong pleochroism (light and dark brown); it was darkest with the light polarized perpendicular to the optic axis. The brown halos surrounding the included crystals suggested that the color might be related to the elements in the inclusions: iron and titanium.

Prior to Eppler (1958), brown beryl from Brazil was described by J. Sinkankas ("Some freaks and rarities among gemstones," Fall 1955 *Gems & Gemology*, pp. 197–202) and E. H. Rutland ("An unusual brown beryl," *The Gemmologist*, Vol. 25, No. 304, 1956, pp. 191–192). More recently, a brown beryl was described in the Winter 1999 Lab Notes section (p. 202). The new material from

Mozambique and the brown beryl described in the Winter 1999 Lab Note share many properties (i.e., color, pleochroism, and lamellar color zoning). The color of that sample was attributed to dense layers of brown inclusions along lamellar "twin" planes, although to this contributor's knowledge twinning in beryl is unknown.

The absorption spectra of brown beryl from Brazil were studied by C. J. Cristino ("Utilisation des techniques de laboratoire de gemmologie sur quelques gemmes brésiliennes," Diplôme d'Université de Gemmologie, University of Nantes, France, 2001). To better ascertain the origin of color in the Mozambique brown beryls, this contributor obtained optical absorption spectra using a Unicam UV4 spectrophotometer. The brown beryls from both Mozambique and Brazil show a progressive increase in absorption from the red to the ultraviolet region, with no other significant absorption features. When the spectrum of an essentially colorless area is subtracted from that of a brown area (with both spectra taken in the same crystallographic orientation from a parallel-window sample), part of a very broad band appears in the blue and violet region. (The short-wave side of this band is extremely difficult to resolve due to the subtraction of two almost vertical curves.) The very broad nature of the band and the strong pleochroism with which it is associated both suggest a charge-transfer phenomenon (see S. M. Mattson and G. R. Rossman, "Identifying characteristics of charge transfer transitions in minerals," *Physics and Chemistry of Minerals*, Vol. 14, 1987, pp. 94–99).

Qualitative chemical analyses of the very light blue and brown areas were obtained with a JEOL 5800 scanning electron microscope equipped with a PGT energy-dispersive secondary X-ray detector. The spot size resolvable by this technique is about 1 μm, and the analyses were done on the broader lamellae (i.e., about 10 μm in thickness). Both the light blue and brown areas showed identical contents of all elements, including iron, within the detection limits. A titanium peak was seen using a long counting time (i.e., 1,000 seconds), but this element was present in concentrations below the detection limit (i.e., about 1,000 ppm) for our analytical routine.

One hypothesis for the origin of the brown color that is consistent with all of the results mentioned above is

Figure 5. When this brown beryl was viewed parallel to the optic axis, skeletal ilmenite inclusions with brown halos could be seen (left; magnified 30×). Perpendicular to the optic axis, several thin, very dark brown lamellae were visible (right; magnified 40×). Photomicrographs by E. Fritsch.



Fe²⁺-Ti⁴⁺ charge transfer (Cristino, 2001). This mechanism typically gives a brown color in most minerals (e.g., dravite tourmaline) except corundum and kyanite, and only extremely low concentrations of Ti are needed. An alternate explanation would be absorption caused by molecular clusters or submicroscopic inclusions of ilmenite, which might still give rise to pleochroism. These hypotheses may also apply to some rare examples of pleochroic brown sillimanite [G. Rossman, pers. comm., 2002]. A detailed investigation using a transmission electron microscope might determine the true coloration mechanism, but this is well beyond the scope of the present study. EF

Yellowish green and green chrysoberyl from Ilakaka, Madagascar. Recently we encountered one yellowish green and one green chrysoberyl (figure 6) in two parcels of faceted yellow chrysoberyls that originated from the large Ilakaka mining area in southern Madagascar. Although greenish yellow to yellowish green chrysoberyl from Ilakaka has been mentioned in the literature (see Summer 1999 Gem News, p. 150, and C. C. Milisenda et al., "New gemstone occurrences in the south-west of Madagascar," *Journal of Gemmology*, Vol. 27, 2001, pp. 385-394), the properties of these gems have not been published. It was particularly interesting for us to evaluate the cause of color in these stones.

According to information from knowledgeable gem traders in Madagascar, yellowish green to green chrysoberyl is rare at Ilakaka, and typically only small stones are found. No distinct color change was observed for either stone; the color was yellowish green or green in daylight and somewhat grayish green in incandescent light. The pleochroism in daylight was yellowish green to bluish green. The R.I. values of the yellowish green stone were 1.740-1.750, and of the green stone, 1.740-1.748 (birefringence 0.010 and 0.008, respectively). These R.I.'s are somewhat lower than

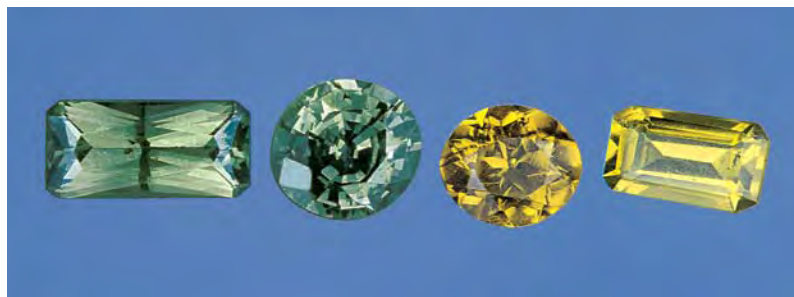


Figure 6. Yellow chrysoberyl from Ilakaka, Madagascar (as seen on the right, 0.42 and 0.37 ct), is typically colored by iron. The yellowish green and green chrysoberyls on the left (0.59 and 0.63 ct), which are also from Ilakaka, owe their color to additional traces of Cr and V. Photo by Maha Tannous.

those commonly reported for chrysoberyl in the literature (1.75-1.76; see R. Webster, *Gems*, 5th ed., revised by P. Read, Butterworth-Heinemann, Oxford, England, 1994, pp. 134-135). The S.G. values of 3.70 and 3.71, obtained by the hydrostatic method, are within the range normally recorded for chrysoberyl. Microscopic examination revealed growth structures, but no mineral inclusions were observed in either sample.

Chemical analyses by electron microprobe (table 1) showed traces of vanadium and chromium (with twice as much V and Cr in the green sample), as well as iron contents of approximately 1 wt.% Fe₂O₃.

Absorption spectroscopy in the UV-Vis range revealed the normal absorption spectrum of Fe³⁺ in chrysoberyl (i.e., absorption bands at 377 and 440 nm), superimposed by weak, broad absorption bands of Cr³⁺ (centered at approximately 426 and 571 nm).

These data indicate that the samples have compositions intermediate between those of yellow chrysoberyl and alexandrite. The Cr and V contents are sufficient to cause a yellowish green or green color (instead of the pure yellow iron-related coloration of Cr- and V-free chrysoberyl), but not high enough to produce the distinct color change characteristic of alexandrite.

KS

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TABLE 1. Physical and chemical properties of two yellowish green and green chrysoberyls from Ilakaka, Madagascar.

Property	Yellowish green	Green
Weight	0.59 ct	0.63 ct
Refractive indices	1.740-1.750	1.740-1.748
Specific gravity	3.70	3.71
Microprobe analyses (wt.%) ^a		
Al ₂ O ₃	78.83	78.74
TiO ₂	0.04	0.10
V ₂ O ₃	0.02	0.05
Cr ₂ O ₃	0.06	0.12
Fe ₂ O ₃ ^b	1.07	1.04
MnO	0.01	0.01

^a Average composition of 10 analyses each.

^b Total iron as Fe₂O₃.

"Tashmarine": Diopside from Central Asia. Columbia Gem House (CGH) of Vancouver, Washington, introduced "Tashmarine" at the June 2002 JCK show in Las Vegas. This yellowish green diopside is sourced from Central Asia, near the borders of China, Kazakhstan, and Uzbekistan. According to CGH president Eric Braunwart and cutting manager Bart Curren, CGH initially purchased 50 kg of rough that was mined in 2001, and has subsequently negotiated an agreement with the miner to purchase his entire

production. So far, two additional shipments weighing a total of about 45 kg have been obtained. Most of the rough is heavily included and must be trimmed extensively in preparation for cutting. The final yield in cut stones has averaged only about 3% from the original rough.

Five faceted stones and three crystals were loaned to GIA by CGH. The crystals, which contained some facetable areas, were well formed with shiny faces (except for some light etching, particularly on the terminations). These large crystals (up to $11.8 \times 3.6 \times 2.5$ cm) appeared very similar to the somewhat smaller diopsides from China that were described in the Summer 1989 Gem News (pp. 111–112). Examination of the cut stones (1.57–25.16 ct; figure 7) by one of us (EQ) showed the following properties: color—light yellowish green to yellowish green, with weak or no pleochroism; R.I.—1.667–1.692 or 1.693 (birefringence 0.025–0.026); S.G.—3.29; Chelsea filter reaction—yellow-green; inert to long- and short-wave UV radiation; and an absorption line at 440 nm, with additional lines at 490, 505, and 550 nm in larger samples, visible with the desk-model spectroscope. These properties are consistent with those reported for diopside by R. Webster (*Gems*, 5th ed., revised by P. Read, Butterworth-Heinemann, Oxford, England, 1994, pp. 330–331), except that the R.I. values in that publication are slightly higher (1.675–1.701). Three of the five stones were free of inclusions. One sample contained a feather and pinpoint inclusions, and another had a minute mineral inclusion. Moderate doubling of the facet junctions was visible in all samples.

Figure 7. Yellowish green diopside from central Asia is being marketed as “Tashmarine.” The gems shown here range up to 25.16 ct; the largest stone displays concave facets. Courtesy of Columbia Gem House; photo by Maha Tannous.



Total reserves are unknown, but Mr. Braunwart expects the deposit will produce about 20 kg of rough per month. The largest crystal acquired so far weighed 1,160 grams. Attractive cut goods are available in sizes up to 35 ct, although most range from 2 to 8 ct. Stones less than 3 ct are generally cut with flat facets, with most larger stones cut using concave facets. Mr. Braunwart reported that the hardness of Tashmarine is 5.5 to 6.0 on the Mohs scale, and it handles “much like tanzanite” in jewelry manufacturing and wear. He added that the material has a very narrow range of color, and does not respond to heat treatment. CGH claims that Tashmarine has not been subjected to any treatments to enhance color or clarity.

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Carved emeralds from the Malagana archeological site in Colombia. A collection of emeralds, which includes 15 carved beads and one natural crystal that are reportedly of pre-Columbian origin, were shown to GIA by Ugo Bagnato. The beads are all carved in a similar primitive style that resembles the example seen in the Winter 1994 Lab Notes section (pp. 264–265). All are drilled (including the crystal), and one contains an open hoop of yellow metal (see, e.g., figure 8).

According to Mr. Bagnato, who obtained the collection about nine years ago, the pieces came from an important archeological site that was discovered in a large sugar cane field called Malagana, near the village of El Bolo in the township of Palmira, which is located northeast of Cali in western Colombia’s Cauca Valley (see also S. Archila, *Los Tesoros de los Señores de Malagana*, Museo del Oro, Banco de la República, Bogotá, Colombia, 1996, 95 pp.). He obtained the stones about three months after the site was discovered by a farmer who found a piece of gold while plowing the field with a tractor. Soon after the discovery, thousands of *guaqueros* (“grave robbers”)—young and old, male and female, of many cultures—began frenzied digging at the ancient tomb site. Thousands of rectangular holes were sunk within a few months. The largest excavation (about 50 m wide) was located near the center of the field, and in it were found the best artifacts. The chaotic situation was monitored by police and military personnel, and the government eventually closed the area, but not before most of the scientific context of this unique archeological discovery was destroyed. In late 1994, archeologists, anthropologists, and other scientists were finally able to begin organized excavation of what remained of the Malagana site.

Most of the artifacts recovered from Malagana consisted of gold, pottery, and quartz; carnelian and green jasper beads also were found, in addition to the carved emeralds (which were relatively rare, according to Mr. Bagnato). The



Figure 8. These five carved beads (4.81–32.66 ct) and one natural crystal of emerald were reportedly recovered from an important archeological site at Malagana, near Cali, Colombia. Photo © Harold & Erica Van Pelt.

age of the treasures is thought to fall anywhere from the 4th century BC to the 2nd century AD. Based on their carving style, Mr. Bagnato believes that the emerald beads originated from the Tairona culture of the Sierra Nevada de Santa Marta mountains in northern Colombia.

A gemological examination of the five carved samples in figure 8 (4.81–32.66 ct) was performed by one of us (EQ). The following characteristics were recorded: color—slightly bluish green; R.I.— $n_o=1.580-1.581$ and $n_e=1.572-1.573$ for three samples with flat polished surfaces, and 1.57 for the other two samples by the spot method; Chelsea filter reaction—red; inert to long- and short-wave UV radiation, except for weak yellow fluorescence to long-wave UV in some fractures in four of the stones; and typical chromium absorption lines in the desk-model spectroscope. Microscopic examination revealed two- and three-phase inclusions, fractures (some containing a colorless or whitish substance), partially healed fractures, and color zoning. These characteristics are consistent with those of Colombian emeralds. The four samples exhibiting yellow fluorescence in some fractures also showed evidence of clarity enhancement when viewed with the microscope.

This collection of carved emerald beads is noteworthy for the number of pieces, as well as for the fine quality of several of the emeralds. The clarity enhancement could have been performed by the dealers who sold the stones, so the presence of a filler does not preclude their reported pre-Columbian origin. It is interesting to note that there are no known emerald deposits in the Cauca Valley region; the famed deposits at Muzo and Chivor lie more than 300 km to the northeast. For additional information on the

Malagana site, see: W. Bray et al., “The Malagana chiefdom, a new discovery in the Cauca Valley of southwestern Colombia,” in A. J. Labbé, Ed., *Shamans, Gods, and Mythic Beasts: Colombian Gold and Ceramics in Antiquity*, American Federation of Arts (New York) and University of Washington Press, 1998, pp. 121–154; and W. Bray, “Malagana and the goldworking tradition of southwest Colombia,” in C. McEwan, Ed., *Precolumbian Gold: Technology, Style and Iconography*, British Museum Press, London, 2000, pp. 94–111.

BML and Elizabeth Quinn

Hemimorphite from Congo. According to Hussain Rezayee and Sherry Shafa of Pearl Gem LA, Los Angeles, in March–April 2002 bright blue, gem-quality hemimorphite was found about 200 km from Brazzaville in southern Congo. Mr. Rezayee reported that specimens from this new locality attain weights of 10–20 kg, but only small portions are suitable for cutting cabochons. Unfortunately there has been no additional production of high-quality material for several months, due to armed conflict between rebels and government forces in the area.

Two freeform cabochons were loaned to GIA for examination. The samples weighed 50.65 and 114.96 ct (see, e.g., figure 9), and the following properties (listed for each stone in that order) were determined by one of us (EQ): color—mottled blue, and banded blue and white; pleochroism—none; diaphaneity—translucent; aggregate reaction with the polariscope; R.I.—1.61 and 1.62, by the spot method (neither piece showed a birefringence “blink,” as would be expected for smithsonite); S.G.—3.41 and 3.34; inert or weak bluish white to long-wave, and weak greenish blue

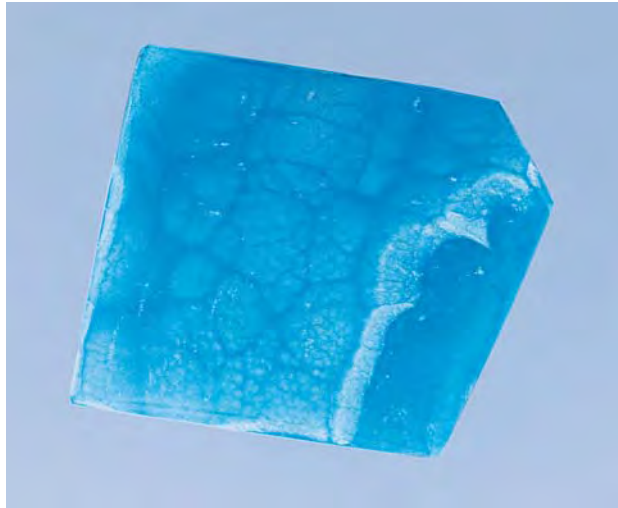


Figure 9. This 114.96 ct hemimorphite was mined from a new locality in southern Congo. Note the botryoidal structure showing through the polished surface. Courtesy of Pearl Gem LA; photo by Maha Tannous.

fluorescence to short-wave UV radiation; and no spectrum seen with the desk-model spectroscope. Both samples displayed a fibrous banded structure and fractures when observed with the microscope, and the larger cabochon also showed a botryoidal structure. This larger piece also showed evidence of a filler in some of the fractures and cavities. Although many of these properties are similar to those reported for hemimorphite in the Lab Notes section (see Spring 1998, pp. 44–45, and p. 254 of this issue), the

Figure 10. In the Erongo Mountains of central Namibia, fine, gem-quality crystals of jeremejevite were mined in 2001 from cavities found above steep granite slopes (beyond the area shown to the upper right). Photo by Georg Gebhard.



S.G. of the larger, banded stone is rather low. Also, the fluorescence noted in this hemimorphite was not present in the other sample. These anomalous characteristics are probably due to the filling substance that was present.

With its bright color and potential for interesting patterns, the Congo hemimorphite could provide an interesting design element for unusual jewelry pieces. However, future production of the material from this politically unstable area remains uncertain.

BML and Elizabeth Quinn

Jeremejevite from the Erongo Mountains, Namibia. In March 2001, attractive gemmy crystals of an intense blue color and a high luster were found in a small miarolitic cavity in granite on the eastern side of the Erongo ring complex in central Namibia (figure 10). Cavities within this area of the Erongo Mountains have been the source of high-quality crystals of aquamarine, black tourmaline, and other minerals since 1999 (see GNI entry on pp. 266–268 of this issue and G. Gebhard, *Minerals from the Erongo Mountains, Namibia*, CD-ROM, January 2002, GG Publishing, Großenseifen, Germany, ggpublishing@t-online.de). The intense blue crystals were found on the Ameib Farm, near the common borders with the Davib Ost and Brabant Farms, at coordinates 21°45'27"S, 015°35'00"E. The crystals were initially believed to be beryl and, due to their relatively small size (<1 cm long), little effort was devoted to finding more. However, this contributor, suspecting they might be a rare mineral, submitted some to Dr. Jochen Schlüter at Hamburg University for examination. X-ray powder diffraction proved that they were jeremejevite.

Requests to the local miners for more of this material soon resulted in the recovery of a few hundred crystals of various colors, but mostly colorless (see G. Gebhard and J. Brunner, "Jeremejevite from Ameib, Erongo, Namibia—A new and probably the best find ever made," http://www.mineralnews.de/New_finds/Jeremejevite/jeremejevite.html, posted May 2001). By the time production ceased in July 2001, several additional pipe-like cavities in the vicinity had yielded between 3,000 and 3,500 crystals, of which 50% were colorless or near colorless and measured up to 1 cm long and 0.1 cm wide. A small portion (about 500) measured 1–3 cm long, and very few attained sizes up to 5 cm. This contributor knows of fewer than 10 crystals that reached 5–7 cm.

The colored crystals varied from pale yellow to many shades of blue, to violet (see, e.g., figure 11). The last color was the least common, in crystals up to 4 cm; the "sky" blue or saturated blue crystals reached up to 7 cm long and 13 g in weight. Although many had surface markings that suggested they were originally intergrown with one another, very few were found in clusters or attached to their feldspar/quartz matrix; almost all were recovered as loose single crystals. They ranged from needle-like to columnar; most were highly transparent, but the cutting

material was limited by the typically small diameter of the crystals (< 3 mm).

Nevertheless, the jeremejevites from the Erongo Mountains are prized for the fine gemstones that have been cut (figure 12). This contributor estimates that only about 1% of the faceted stones exceed 1 ct. A few (probably less than 10 stones) range up to 5 ct. The largest cut stone, at almost 13 ct, is truly exceptional (figure 13).

Three faceted jeremejevites (0.48, 0.62, and 0.80 ct) were supplied to GIA for examination. Elizabeth Quinn at the GIA Gem Trade Laboratory in Carlsbad determined the following characteristics: color—very light blue to blue, with slightly darker blue bands visible in the lighter stones; pleochroism—moderate to strong, in blue to near-colorless hues; R.I.—1.639–1.640 and 1.648–1.649 (birefringence 0.009); S.G.—3.29–3.32; inert to long- and short-wave UV radiation; and no features seen with the desk-model spectroscope. Magnification revealed partially healed fractures and “fingerprints,” as well as mineral inclusions. These characteristics are consistent with those reported by K. Scarratt et al. (“Jeremejevite: A gemological update,” Fall 2001 *Gems and Gemology*, pp. 206–211).

Two jeremejevite crystals, one colorless and the other blue, were submitted to Dr. Schlüter and colleagues at Hamburg University for electron microprobe analysis. The data showed the Al and F contents expected for jeremejevite, and no trace elements were detected. However, using energy-dispersive X-ray fluorescence (EDXRF) spectroscopy, a technique that is more sensitive to trace elements, Dr. George Rossman (California Institute of Technology, Pasadena) has confirmed the presence of iron in blue jeremejevite from the Erongo Mountains; he feels that the color is caused by Fe^{2+} - Fe^{3+} intervalence charge transfer (G. Rossman, pers. comm., 2002).

The spectacular jeremejevite finds in the Erongo Mountains have supplied some of the world’s largest and

Figure 11. These transparent crystals (up to 4.6 cm long) of jeremejevite from the Erongo Mountains show a variety of colors, including pale yellow, blue to greenish blue, and violet. Photo by Georg Gebhard.



Figure 12. The violet color of these crystals (2.7 and 3.3 cm long) is rare in jeremejevite from the Erongo Mountains. More commonly, the material ranges from colorless to blue (usually with color banding), as shown by these relatively large faceted stones (2.92–4.10 ct). Courtesy of Georg Gebhard; photo by Maha Tannous.

finest single crystals, as well as some of the best faceted stones in terms of size and quality. The deposit now appears exhausted, despite further mining and exploration in the area, there has been no significant production since July 2001.

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New morganite mine in Madagascar. At the June 2002 JCK show in Las Vegas, Tom Cushman of Allerton Cushman & Co., Sun Valley, Idaho, had some attractive morganites from a new find in Madagascar. The facet rough was derived from large, fractured crystals that came from a pegmatite in the Fianarantsoa district of south-central Madagascar, in the Ambositra area. Mr. Cushman has obtained about 3.5 kg of rough, and the stones are typically faceted in sizes ranging from 6 × 4 to 8 × 6 mm (i.e., approximately 0.4–1.2 ct, although he has seen gems up to 9 ct). He estimates that several hundred carats have been faceted. The color is fairly

Figure 13. At 12.92 ct, this is the largest faceted jeremejevite from the Erongo Mountains that is known to this contributor. Faceted by Helmut Schäfer, Walter Bohrer Co., Idar-Oberstein, Germany; photo by Georg Gebhard.





Figure 14. These three morganites (3.34–4.19 ct) were obtained recently from a new pegmatite mine near Ambositra in south-central Madagascar. Courtesy of Allerton Cushman & Co.; photo by Maha Tannous.

consistent, resembling saturated rose quartz. Most of the material is “peach” colored when mined, and turns pink after exposure to sunlight for a few hours or days. According to Federico Pezzotta (Museo Civico di Storia Naturale, Milan, Italy), the “pinking” is also done in Madagascar by brief exposure to an alcohol flame.

Three of the morganites (3.34–4.19 ct; figure 14) were loaned to GIA for examination, and the following properties were determined by one of us (EQ): color—light pink, slightly purplish and orangy pink; R.I.— $n_o = 1.586\text{--}1.587$ and $n_e = 1.578\text{--}1.579$ (birefringence—0.008); S.G.—2.75; inert to long-wave and very weak chalky green fluorescence to short-wave UV radiation; and no absorption features observed with the desk-model spectroscope. Microscopic examination revealed needles, fractures, “fingerprints,” and pinpoint inclusions.

Figure 15. The color of these unheated aquamarines (3.14 and 3.53 ct) is representative of the finest material from the Erongo Mountains of Namibia. Courtesy of Chris Johnston; photo by Maha Tannous.



Although Mr. Cushman was not aware of any clarity enhancements, the fractures showed low relief, and some contained air bubbles, indicating the presence of a filling substance. On returning to Madagascar in July–August 2002, he learned that some of the material is placed in a dilute honey solution by local dealers, to improve the appearance of the rough. There is also a possibility that cutting oil entered some of the fractures during the initial processing of the rough.

Mr. Cushman helped direct mining activities when he visited the deposit in August, and is optimistic that the pegmatite will yield more gem-quality morganite. Due to the recent political and logistical problems in Madagascar, however, access to the area is difficult.

BML and Elizabeth Quinn

Update on some Namibian gem localities. In conjunction with his attendance at a geological conference in Namibia in July 2002 (see GNI report on pp. 273–274), GNI editor Brendan Laurs visited some granitic pegmatite–hosted gem deposits in central Namibia. Most were seen on a pre-meeting field trip led by Drs. G. I. C. Schneider (Geological Survey of Namibia, Windhoek) and J. A. Kinnaird and Paul Nex (University of the Witwatersrand, Johannesburg, South Africa).

The deposits of topaz and aquamarine at **Klein Spitzkoppe** (see article by B. Cairncross et al. in the Summer 1998 issue of *G&G*, pp. 114–125) were visited first. The gem crystals formed in miarolitic cavities (i.e., open “pockets”) within Early Cretaceous granites and associated pegmatites. These granites are similar in age to those in the Erongo Mountains, but are significantly younger than other pegmatitic gem deposits in Namibia, which are of late Pan-African age (approximately 520 million years old). Local people continue to mine both primary and secondary deposits around Klein Spitzkoppe, although most have left the area for Erongo.

Figure 16. The Usakos pegmatite near Usakos, Namibia, is being actively mined for gem tourmaline in a large open pit. Photo by Brendan M. Laurs.



According to Chris Johnston (Johnston-Namibia C.C., Omaruru, Namibia), about 300–400 people are working the **Erongo** deposits. For the past four years, miarolitic cavities in granites and pegmatites on the northern side of the Erongo igneous complex have yielded attractive, occasionally world-class crystal specimens of aquamarine, black tourmaline, smoky quartz, feldspars, fluorite, and other minerals (see S. Jahn and U. Bahmann, "Die Miarolen im Erongo-Granit. . .," *Mineralien-Welt*, Vol. 11, No. 6, 2000, pp. 42–56). More recently, in March 2001, a significant find of gem-quality jeremejevite was made in the area (see separate GNI entry in this issue and W. E. Wilson et al., "Jeremejevite from Namibia," *Mineralogical Record*, Vol. 33, 2002, pp. 289–301, abstracted in this issue). Most of the Erongo crystals are sold as mineral specimens, although some attractive aquamarines (see figure 15) and jeremejevites have been faceted. Much of the production initially came from near-surface cavities, but now the miners must dig 4–5 m to reach productive areas and they do not have access to explosives. A few use pneumatic hammers or heavy-duty electric hammer drills, but most dig by hand, working in small groups. An abundance of Erongo material was being sold along the road to Klein Spitzkoppe, together with minerals from elsewhere in Namibia.

The **Usakos** tourmaline mine (figure 16), located a few kilometers southwest of the town of Usakos, is being actively worked by Jo-Hannes Brunner and partners. They purchased the property from Rochelle Mansfield, daughter of well-known Namibian gem and mineral dealer Sid Pieters, in late 2000—shortly after a rich pocket of gemmy greenish blue tourmaline was found (see, e.g., photo in Winter 2000 *G&G*, p. 322). A team of six miners is enlarging the open pit by drilling and blasting; debris is removed using a front-end loader. Over the past two years, numerous small cavities have yielded gem tourmaline in a wide range of colors (figure 17, top). However, finding the cavities in the large pegmatite has proved difficult due to their irregular distribution, as well as the lack of recognizable mineralogical or textural zoning that can be used to indicate probable areas of mineralization. According to Mr. Brunner, approximately 300 kg of tourmaline (mostly green to blue-green) has been recovered since his group began mining the deposit, but only a small percentage was gem quality. Most of the tourmaline is heated before cutting to brighten the colors. Also, when heated up to 700°C, some of the blue-green tourmalines become an attractive light green. All of the colors achieved with heat treatment have also been found naturally at the mine.

One of Namibia's most important gem tourmaline deposits is **Neu Schwaben** in the Karibib area, which produced large quantities of clean, attractive stones in bright blue-to-green colors during 1996–1997 (figure 17, center; see also Spring 1997 *Gem News*, pp. 66–67). Since then, organized mining has been hampered by social and political problems. Currently there are approximately 200 local miners working the primary and alluvial deposits associat-

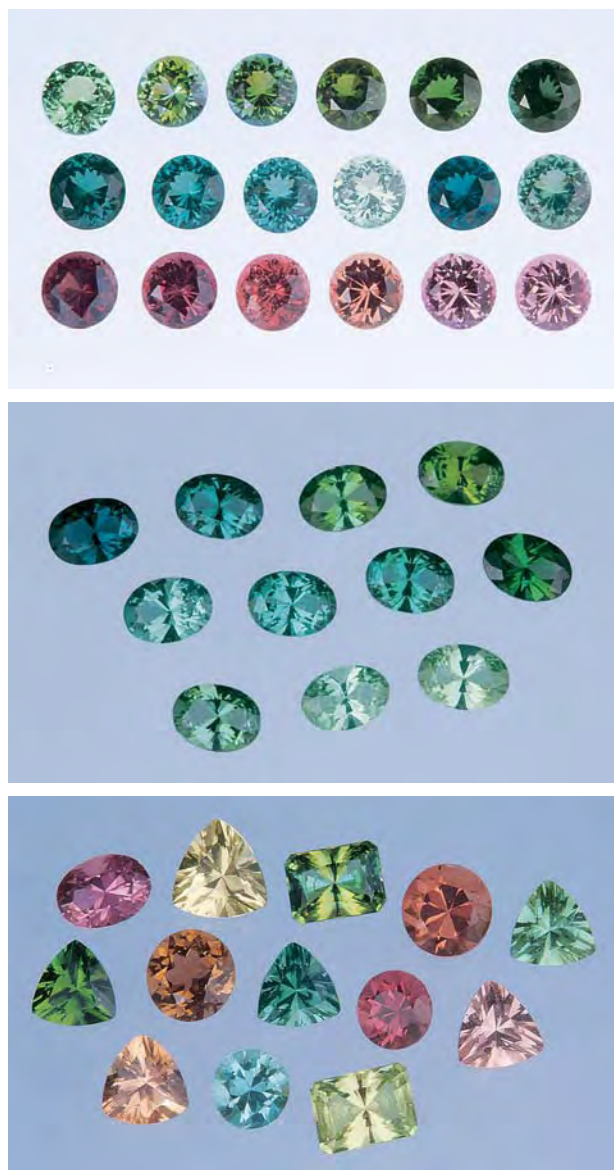


Figure 17. Tourmaline from Namibia comes in a range of colors, even from a single mine. These photos show the representative color range of tourmalines from the Usakos mine (top, approximately 0.50 ct each), Neu Schwaben (center, approximately 0.40 ct each), and Omapyo (bottom, 0.60–1.10 ct). Nearly all of the tourmalines have been heated to lighten their tone or remove a brown hue. Courtesy of Jo-Hannes Brunner (top) and Chris Johnston (center and bottom); photos by Maha Tannous.

ed with the large pegmatite. Production has been small and sporadic, due to the difficult working conditions and disorganized mining. A cooperative initiative under consideration would grant legitimate title of the mining rights to a nonprofit trust formed on behalf of the independent



Figure 18. These matrix opals (up to 21 × 18 mm) are from Piauí State in Brazil. Photo by Jaroslav Hyrsl.

diggers. The mining license is expected to be granted by the end of 2002.

The **Otjua** pegmatite in the Karibib area became famous during the period 1985–1990, when a 45-m-deep cavity excavated by the present mine owner (Hannes Kleynhans) yielded enormous clusters of smoky quartz (see Fall 1989 Gem News, p. 180). Specimens from the mine, including a quartz cluster weighing 14.1 tonnes and faceted tourmalines in a variety of colors, are on display at the Kristall Galerie museum in Swakopmund.

Many decorative mineral specimens from this mine were sold in the U.S. during the early 1990s by Bryan Lees (Collectors Edge, Golden, Colorado). Mr. Lees (pers. comm., 2002) reported that gem tourmaline was recovered

Figure 19. White matrix opal from Piauí, Brazil, is treated to black to enhance the play-of-color. The bottom-center stone is 16 × 10 mm; photo by Jaroslav Hyrsl.



from the pegmatite “pockets” and large quantities of melee-sized rough (ranging from green to purple to red, in particular) also were extracted from tourmaline in the crystallized wall rock of the pocket zones.

The pegmatite has been mined in an elongate open cut and shallow tunnels, and measures up to 40 m wide and at least 100 m long. It dips moderately to steeply northward, and has intruded along the contact between marble (to the north) and a dark-colored, fine-grained metamorphic rock (to the south). According to Mr. Kleynhans, the large quartz crystal “cave” was found at the western end of the open pit, whereas the eastern end subsequently produced about 120 small cavities that contained smoky quartz and/or light green tourmaline. At the time of our visit, there had been no mining activity at Otjua since January 2001, mainly due to disputes over the mineral rights. However, Mr. Kleynhans reports that these problems are now resolved, and he has resumed mining of the pegmatite.

Significant quantities of gem tourmaline also have been recovered from several pegmatites that collectively are referred to as the **Omapyo** mine (originally called the Chandler mine), located approximately 35 km southeast of Omaruru. The pegmatites are hosted by fine-grained mica schists, dip moderately southeast, and range up to ~4 m thick. According to Chris Johnston, the property was claimed in the 1980s by Gawie Cloete, who worked it intermittently for about 10 years, hitting one particularly profitable pocket in the early 1990s. The property later changed hands and eventually fell under the control of the Namibian government. Over the past three years, a government-funded company known as the Development Brigade Corp. worked one of the pegmatites, and another pit was dug nearby by John Alcott, an independent miner based in Karibib. Mr. Johnston estimates the total production over the past 20 years at about 50 kg of good gem tourmaline. This mining area has produced a particularly wide range of hues, including some unusual colors (figure 17, bottom). Although currently inactive, Omapyo has the potential to produce significant tourmalines in the future.

Some interesting new opals from Brazil. For years, Piauí State in northern Brazil has been a source of white opal, often with a pronounced layered texture. Matrix opal has been produced there less commonly (see Gem News, Spring 1994, p. 52, and Spring 1999, p. 53), and in July 2001 this contributor obtained some polished natural-color Piauí opal with matrix in Brazil (figure 18). Although some pieces resemble a doublet when viewed from the side, they can easily be distinguished by the irregular boundary between the opal and its matrix. The host rock is gray to light brown sandstone, and is quite distinctive from the darker, finer-grained ironstone matrix associated with boulder opal from Queensland, Australia.

Piauí is also the source of white matrix opal that is treated to black by an undisclosed process to enhance the play-of-color (figure 19). The material is locally referred to

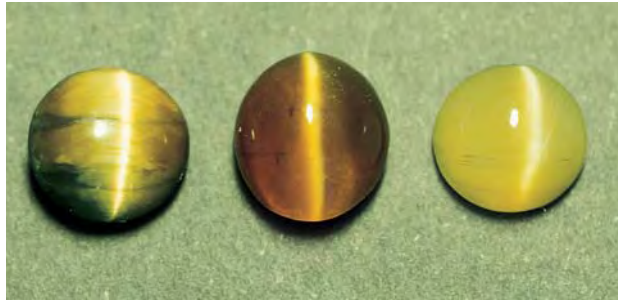


Figure 20. Attractive cat's-eye opal recently became available in Brazil. The center stone weighs 2.37 ct; photo by Jaroslav Hyrsl.

as "queimado" ("burned") and looks very similar to the treated matrix opal from Andamooka, South Australia, described by G. Brown ("Treated Andamooka matrix opal," Summer 1991 *Gems & Gemology*, pp. 100–106). Concentrations of black color between the grains, easily seen with a loupe, readily identify this material as treated. During a recent (July 2002) trip to Brazil, this contributor noted that thousands of these treated opals were available.

Cat's-eye opal from northern Bahia State (see Spring 1994 *Gem News*, p. 52) is typically of low quality. However, much better-quality material, reportedly from the same locality, appeared on the Brazilian market in July 2001. This new opal is semitransparent and has a yellow to "honey" brown color and a sharp eye (figure 20). In 2001, stones exceeding 5 ct were available, and the best pieces were comparable to those from Tanzania (see Summer 1998 *Gem News*, pp. 138–140). This contributor saw a few hundred carats in Brazil in 2002.

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Bicolored spessartine from Brazil. Natural garnets often are chemically zoned, but color zoning in gem-quality garnets is uncommon. There are only a few examples of gem garnets with color zoning in the literature (see, e.g., *Gem News*, Winter 1990, pp. 303–304, and Fall 1997, pp. 224–225).

Five bicolored orange and orangy brown garnets were purchased in Brazil in July 2001 by one of these contributors (JH). They ranged from 0.96 to 5.61 ct (see, e.g., figure 21). According to the cutter, they were mined from the famous Galilea pegmatite region near Governador Valadares. This area has long produced orange to reddish brown spessartines, but these five samples are the only bicolored Galilea garnets this contributor has seen.

The diaphaneity of the five samples varied according to the color, from transparent (the orange zones) to translucent (the orangy brown portions). Specific gravity values ranged from 4.10 to 4.25. As with the garnets in the *Gem News* items cited above, the refractive index varied slightly within each of the five samples, from about 1.80 in the orange area to about 1.81 in the orangy brown zone, as measured with a Gemeter reflectometer (Sarasota Instruments). With a handheld spectrocope, the orange

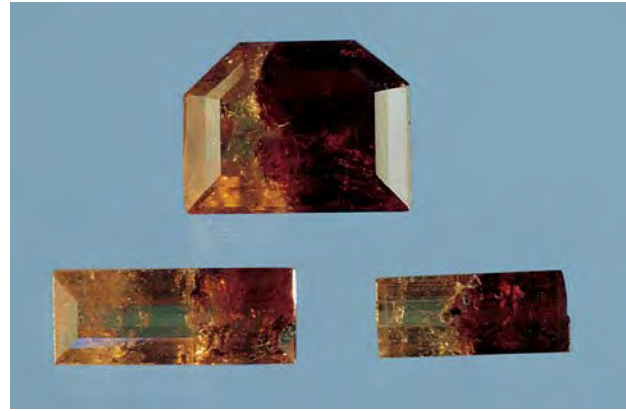


Figure 21. These bicolored spessartines from Brazil (up to 5.61 ct) show distinct orange and orangy brown portions. Photo by J. Hyrsl.

zone in each sample showed a typical spessartine spectrum (of weak intensity), while the orangy brown portions were too dark to obtain a spectrum. The two color zones also showed differences when examined with magnification. In the orange part the color was homogeneous, but swirl-like growth features were evident as well as (in places) a granular structure, sometimes with black grain boundaries. The orangy brown area was itself color zoned, with rounded areas of darker color; it also contained veils of two-phase (liquid and gas) inclusions and jagged, saw-blade-like growth structures. Near the boundary between the orange and orangy brown zones in all five samples were numerous euhedral to rounded, strongly anisotropic crystals (figure 22).

To better understand the nature of the zoning, we studied a 0.96 ct rectangular cut stone in detail. We obtained chemical analyses using an energy-dispersive PGT detector coupled with a JEOL 5800 scanning electron micro-

Figure 22. Elongated two-phase inclusions and anisotropic rounded crystals are present in the orangy brown part of this bicolored spessartine. Photomicrograph by J. Hyrsl; field of view is 3.5 mm.

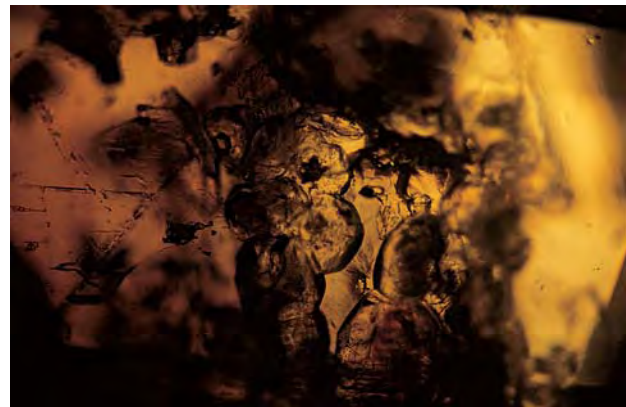




Figure 23. Gem-quality pink/yellow spodumene was recovered from Laghman Province, Afghanistan, in October 2001. The crystal shown here weighs 734 grams, and the faceted stones weigh 226.95 and 168.80 ct. Courtesy of Dudley Blauwet Gems; photo by Jeff Scovil.

scope, and UV-Vis absorption spectra using a Unicam UV4 spectrophotometer. We found a higher iron content in the orangy brown zone than in the orange part (1.3 vs. 0.8 atomic % Fe, the other components being nearly constant), but it was difficult to measure accurately due to interference in the detection of Fe and Mn with this technique. However, the only difference between the two colored portions in their visible-range absorption spectra was a gradually increasing continuum from the near-infrared toward the UV region; the typical spessartine spectrum was superimposed over this continuum in the orangy brown portion, whereas the continuum was absent in the lighter orange zone. (An almandine component was not obvious in either portion.) It is well known that this increasing continuum is due to Fe^{2+} - Ti^{4+} charge transfer (see R. K. Moore and W. B. White, "Intervalence electron transfer effects in the spectra of the melanite garnets," *American Mineralogist*, Vol. 56, 1971, pp. 826-840). Titanium was below the detection limit of our instrument (about 1,000 ppm) in both parts of the stone, but the Ti concentrations necessary for the charge transfer are much less than 1,000 ppm. The color zoning caused by this charge transfer may be explained by variations in iron concentration, a zonation in titanium concentration that we could not measure, or a combination of both.

EF and Jaroslav Hyrsl

Pink/yellow spodumene from Afghanistan. For nearly three decades, large, well-formed crystals and attractive

faceted stones of spodumene from Afghanistan have been coveted by gem and mineral collectors. The crystals are commonly blue-violet or green when mined, and turn pink after brief exposure to sunlight (see G. W. Bowersox, "A status report on gemstones from Afghanistan," Winter 1985 *Gems & Gemology*, pp. 192-204). Gems cut from Afghan spodumene (as from other localities) are most commonly of the pink variety, kunzite. However, significant amounts of large bicolored pink/yellow spodumene crystals were produced last year, which yielded some interesting faceted gems (figure 23). According to Dudley Blauwet (Dudley Blauwet Gems, Louisville, Colorado), the find occurred in October 2001, at a pegmatite near Khauraz in Laghman Province. He obtained 14 kg of material, about half of which was gem quality. Several large stones have been cut; the largest faceted so far by Mr. Blauwet weighs 243.15 ct.

Gemological properties were obtained by one of us (EQ) on two faceted spodumenes that Mr. Blauwet donated to GIA. These oval modified brilliants weigh 45.31 and 205.02 ct; the smaller one has a light orangy brown face-up appearance that results from the combination of yellow and pink hues, and the larger one is greenish yellow. Both show weak to moderate pleochroism—light brownish pink and light brown-orange in the smaller sample, and yellowish brown and greenish yellow in the larger stone. The R.I. values recorded were 1.660-1.676 and 1.661-1.677, respectively, both yielding a birefringence of 0.016. The stones showed weak to moderate orange fluorescence to long-wave UV radiation, and were inert to short-wave UV. Both also showed a single absorption band at 438 nm when examined with a desk-model spectroscope. Microscopic examination revealed a twin plane and needle-like tubes in the small stone, and the same internal features in the large stone along with "fingerprints," three-phase inclusions, and crystals that were transparent, birefringent, and appeared near colorless to pale brown. The properties of these stones are generally consistent with those listed for kunzite by Bowersox (1985) and for spodumene in general by R. Webster (*Gems*, 5th ed., revised by P. Read, Butterworth-Heinemann, Oxford, England, 1994, pp. 186-187).

On one occasion, yellow spodumene submitted to the GIA Gem Trade Laboratory was radioactive due to irradiation with neutrons (G. R. Rossman and Y. Qiu, "Radioactive irradiated spodumene," Summer 1982 *Gems & Gemology*, pp. 87-89). Testing of the present samples with a Geiger counter revealed no evidence of radioactivity.

BML and Elizabeth Quinn

SYNTHETICS AND SIMULANTS

Some glass imitations encountered in Namibia. While in central Namibia in July 2002, GNI editor Brendan Laurs encountered two examples of imitation gem rough (figure 24). Both subsequently were confirmed as glass by Phil



Figure 24. These glass imitations of amethyst (3.9 × 2.3 cm) and tourmaline (2.5 × 0.7 cm) were recently encountered in Namibia. Photo by Maha Tannous.

Owens of the GIA Gem Trade Laboratory in Carlsbad, using Fourier transfer infrared (FTIR) spectroscopy.

In Karibib, a local dealer had a small parcel of rough amethyst that was reportedly from the Platveld area in Namibia. One piece was noticeably larger and more transparent than the others, although the color was typical for amethyst. Examination with 10× magnification revealed several gas bubbles, one of which was also noticeable to the unaided eye. Swirled growth zoning could also be seen, along with a partially healed fracture. The dealer obtained the material from an associate in Karibib, apparently without knowing that the parcel contained a fake.

In Omaruru, gem and mineral dealer Chris Johnston (Johnston-Namibia C.C.) had a glass imitation of a tourmaline crystal that was obtained from local dealers. The dark bluish green color was typical of tourmaline that is mined in the Karibib area. The shape of the “crystal” also was convincing, and the surfaces were partially rounded to give an abraded appearance. However, the striations that are typical of tourmaline were absent, and close inspection revealed that some of the edges were not quite parallel. The imitation also had a lighter heft than would be expected for tourmaline, and felt “warmer” to the touch than a natural stone. Microscopic examination revealed several minute gas bubbles and curved growth zoning, which are typical of glass.

Although convincing at first sight, both imitations could be easily identified in the field by careful observation of their surface and internal features with 10× magnification.

Plastic and steel pearl imitations. During the Basel World Watch & Jewellery Show in April 2002, the SSEF Swiss Gemmological Institute received three parcels of predominantly small brownish gray to dark gray and pink “pearls” for testing (some of which are shown in figure 25). The 548 samples were all undrilled, and ranged from approximately 2 to 12 mm in diameter. They were round to button shaped, drop shaped, and baroque. At first glance, all looked quite convincing. However, when they were

immersed in carbon tetrachloride for X-radiography, two black, slightly baroque samples (each approximately 3 mm in diameter) were seen to float, which indicated they were imitations. When examined with a gemological microscope, these two samples revealed a slightly uneven, granular surface. They also appeared to be very soft, as evidenced by the fact that when tested with a needle on an inconspicuous spot, the surface was indented. A hot point applied to the surface produced a typical smell of burned plastic. On the basis of these characteristics, these “pearls” were identified as black plastic.

X-radiographs revealed a second pair of imitations in the same parcel. Both were perfectly round (4.75 mm in diameter) and showed complete absorption of X-rays. Microscopic examination of these silvery gray spheres revealed small brownish spots on their surface, but not the suture lines that are commonly seen on natural or cultured pearls. Also, each weighed approximately 2.20 ct, which is about three times greater than genuine pearls of similar dimension. Qualitative chemical analysis with EDXRF spectrometry revealed only iron with a trace of titanium. On the basis of these combined characteristics, these spheres were identified as steel. All of the other samples in the parcel revealed features characteristic of natural (i.e., not cultured) pearls in the X-radiographs.

Although the SSEF laboratory has seen plastic imitation pearls on occasion, these are the first steel imitations that we have encountered.

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Figure 25. The samples on the left are representative of three parcels of natural pearls obtained by SSEF for identification last April. In one of the parcels were the two black samples in the middle (~3 mm each, which proved to be plastic imitations) and the two silvery gray spheres (4.75 mm each) on the right, which are made of steel. Photo by Michael S. Krzemnicki; © SSEF Swiss Gemmological Institute.



MISCELLANEOUS

Gem cutting factories in Namibia. While visiting Namibia for a geological conference in July 2002 (see GNI report on pp. 273), GNI editor Brendan Laurs visited two diamond cutting factories in Windhoek. These visits were arranged by Kennedy Hamutenya, who is the diamond commissioner at Namibia's Ministry of Mines and Energy. According to Mr. Hamutenya, there are currently five diamond cutting factories in Namibia. The first one—Namgem Diamond Manufacturing Co., a subsidiary of Namdeb Diamond Corp.—opened in August 1998 in Okahandja (about 70 km north of Windhoek). There are three factories in Windhoek: NamCot Diamonds, Hardstone Processing, and Nam Diamonds Inc. Another diamond cutting operation, run by the Russian company Mars Investment Holding, is located in Walvis Bay on the central coast.

At NamCot Diamonds, general manager Eyal Laybel explained that the factory was opened by Steinmetz Diamond Group, a DTC sightholder. Cutting operations began in May 2001, and the facility officially opened in October 2001. All of the workers are local Namibians who have completed the company's intensive training program. At the time of the site visit, there were 56 diamond polishers working with plans to expand to 80 polishers (for a total of 120 employees). State-of-the-art equipment is used, including customized brutting machines and a computerized proportion analyzer. Mr. Laybel is happy with the results, and indicated that 1+ ct diamonds are now routinely being cut by some workers in the factory (figure 26).

The Nam Diamonds factory, which is operated by Pro Diamonds Manufacturing (Pty) Ltd. in Windhoek, is Namibia's newest diamond cutting and jewelry manufacturing center; it officially opened in July 2002. The facility cost US\$1.8 million and employs 40 people, and will expand to

Figure 26. At the NamCot factory in Windhoek, Namibia, diamond cutter Ipangelwa Gelasius (left) routinely facets 1+ ct diamonds. Photo by Brendan M. Laurs.



70–80 employees as training is completed. Chief executive officer Andrew Clocanas indicated that labor costs in Namibia are comparable to the middle range of Asian wages. He explained that with the support of the Namibian government, the company plans to cut diamonds and colored stones, design and manufacture a diverse jewelry line, and develop an “indigenous branding concept.” Diamonds from Namibia and elsewhere will be cut at the Windhoek facility, and Mr. Clocanas expects that initially 5,000–10,000 carats of diamonds will be faceted each month. Namibian colored stones—such as tourmaline, aquamarine, and garnet—will be faceted in a new factory located in Karibib (165 km northwest of Windhoek). This facility, referred to as Progem, will initially employ approximately 15–20 workers; the number is scalable based on training and market demand. A modern casting facility at the Windhoek factory will have the capacity to manufacture 1,000–2,000 pieces of jewelry per month in yellow and white gold.

In the near future, plans call for a major diamond manufacturing company to open a much larger cutting factory in Windhoek, which is slated to employ 500 workers. Clearly, diamond manufacturers are very interested in taking advantage of the savings offered by Namibia's tax-free EPZ (Export Processing Zone) program, which was activated in 1996. The resulting employment opportunities for Namibians are also contributing to the economic development of the country.

CONFERENCE REPORTS

Gemstone Deposits of Colorado and the Rocky Mountain Region. More than 100 people attended this educational symposium, which was held at the Colorado School of Mines in Golden on September 7–10, 2002. The event was sponsored by several organizations, including the Colorado chapter of the Friends of Mineralogy, the Colorado School of Mines Geology Museum, the Denver Museum of Nature and Science, and the U.S. Geological Survey. Presentations by 22 speakers occurred over two days, and field trips over the next two days included a visit to the Kelsey Lake diamond mine in the State Line district along the Colorado-Wyoming border.

Dr. Jack Murphy of the Denver Museum of Nature and Science explained the development of a Colorado gem and mineral database and locality map, which will employ GIS (Geographic Information System) software and include listings for aquamarine, topaz, diamond, amethyst, turquoise, and lapis lazuli. **Bryan Lees** of Sweet Home Rhodo Inc. in Golden reported on exploration activities for gem-quality rhodochrosite at the Sweet Home Mine near Alma, Colorado; geologic mapping, structural analysis, and geochemical data (As/Sb ratios) have all proved useful. **Howard Coopersmith** of the Great Western Diamond Company in Fort Collins, Colorado, reviewed the discovery (in 1987) and current status of the Kelsey Lake diamond mine. Although not currently in operation, the mine has yielded some large

stones (e.g., 28.2 and 28.3 ct) since production began in 1996. **Dan Kile** of the U.S. Geological Survey in Boulder, Colorado, discussed the formation of agate “thunder eggs” from Del Norte, Colorado. The “plume” and “moss” structures probably resulted from the rhythmic precipitation of Fe- and Mn-compounds within a colloidal silica suspension that subsequently crystallized to form concentrically banded chalcedony. **Dr. Peter Modreski** of the U.S. Geological Survey in Denver reviewed the occurrences of topaz and turquoise in Colorado. The most important localities for topaz are in the Pikes Peak batholith, whereas turquoise is produced from the Florence mine at Cripple Creek. Colorado peridot localities were reviewed by **John Rhoads** of D&J Rare Gems Ltd. in Salida, Colorado. The faceted peridot is attractive, but small: Most stones weigh less than 1 ct, and the largest is 2.47 ct. **Tom Michalski** of the U.S. Geological Survey in Denver described four localities for gem-quality amethyst within Colorado; the best gem material has come from calcite-rich veins at the Amethyst Queen mine in Mesa County.

Efforts to discover the source of the major deposits of alluvial sapphires in Montana were discussed by **Dr. Richard Berg** of the Montana Bureau of Mines and Geology in Butte. Although their origin is still under debate, the sapphires were probably derived from Tertiary volcanic rocks. **David Baker** (Little Belt Consulting Services, Monarch, Montana) and **Dr. Lee Groat** (University of British Columbia, Canada) proposed that sapphires from Yogo Gulch, Montana, formed due to contact metamorphism between magma and metasedimentary host rock in the lower crust. **Leigh Freeman**, a consultant in Evergreen, Colorado, reported that 1,900 carats of sapphires were faceted in 2001 from the Vortex mine near Yogo Gulch; as of July 2002, 2,500 carats had been cut and an additional 1,500 carats were anticipated by the year’s end. **W. Dan Hausel** of the Wyoming State Geological Survey in Laramie summarized historical and newly discovered occurrences of gems in that state, which include nephrite jade, diamond, iolite, and sapphire. He also described the infamous 1872 hoax in which prominent individuals invested significant money in a false occurrence of diamonds in northwestern Colorado (ironically, however, in the vicinity of diamonds found along the Colorado-Wyoming border a century later).

Dr. James Shigley of GIA Research described the formation of gem-quality red beryl in the Wah Wah Mountains of southwestern Utah. The beryl formed in fractures within the 22-million-year-old altered rhyolite, probably as a result of the interaction between magmatic fluids, groundwater, and preexisting minerals. **Michael Gray** of Coast-to-Coast Rare Stones in Missoula, Montana, provided a summary of the largest faceted colored stones that are known from localities in the Rocky Mountain region, such as a 111.42 ct aquamarine from the Sawtooth Mountains, Idaho. **David Wilson** of Precious Gems and Jewelry in Colorado Springs discussed the mining of “sun-

stone” plagioclase feldspar near Plush, Oregon, which owes its schiller to tiny copper inclusions.

*JES and
Michael Gray
Coast-to-Coast Rare Stones
Missoula, Montana*

Gemological reports at Namibian geological conference.

The 11th Symposium of the International Association on the Genesis of Ore Deposits was presented together with the Geological Society of South Africa’s biennial Geocongress meeting in Windhoek, Namibia, on July 22–26. Nearly 400 delegates from 44 countries were present, and approximately 240 presentations were given. GNI editor Brendan Laurs attended the conference, and supplied this report on presentations of gemological significance.

Dr. I. J. Basson (University of Cape Town, South Africa) and coauthors examined the structural controls of kimberlite emplacement in Southern Africa. They correlated the peak of kimberlite emplacement in this region—which occurred during the Cretaceous Period, from 124 to 83 million years (My) ago—to several factors, including accelerated plate motion, above-normal mantle convection and temperatures, and alignment of minerals in the mantle. **R. J. Jacob** (University of Glasgow, U.K.) and co-workers studied alluvial diamond deposits in the lower 250 km of the Orange River (between South Africa and Namibia). Most of the diamonds were deposited in bedrock trap sites or in stationary areas of turbulence within Miocene age (17.5–19 My) gravels.

Marine diamonds are found in a variety of depositional settings, and **L. Apollus** (Namdeb Diamond Corp., Windhoek) and colleagues studied their distribution in pocket beach gravels about 100 km north of the present Orange River delta. Relatively higher diamond grades were found at the northern end of the beach, where the northward-directed wave energy was concentrated against a rocky headland. In the shallow marine environment, **C. M. August** (Namdeb Diamond Corp., Windhoek) and co-workers described how two sophisticated geophysical techniques are used to distinguish potentially diamond-bearing gravels on the seafloor: Side-scan sonar generates detailed elevation maps of the seafloor and another technique called “chirp sub-bottom profiling” provides data on subsurface features (down to 10 m). These techniques have also been used further offshore, as described by **R. Gray** (De Beers Marine, Cape Town, South Africa), to locate what is probably the former Orange River delta. The geophysical data suggest the ancient delta is located 20 km north and 15 km offshore of the present river mouth, at water depths ranging from 90 to 120 m; the sedimentary deposits consist of conglomerates and diamondiferous gravels that are partially covered by recent sands.

Colored stone presentations focused mainly on gems derived from granitic pegmatites. **Dr. J. A. Kinnaird** (University of the Witwatersrand, Johannesburg, South Africa) provided a status report on the development of gem



Figure 27. In Somaliland, emeralds are mined from small pits, such as this one at Simodi (left). Some attractive emerald crystals have been found in that country (right). Gem miners and dealers in Somaliland have recently benefited from training in gem identification and proper small-scale mining techniques. Photos by J. A. Kinnaird.

deposits in Somaliland. Aquamarine and emerald (figure 27) are being mined at several localities in an east-west trending belt parallel to the Gulf of Aden, and the country also contains significant deposits of opal and garnets. **Dr. C. Preinfalk** (University of Munich, Germany) and coauthors evaluated the mineralization potential of gem-bearing granitic pegmatites in Minas Gerais, Brazil. Trace-element data from K-feldspar and muscovite samples indicate that the Araçuaí and Safira districts contain the most geochemically evolved pegmatites, as well as those showing the widest range of evolution; these districts host important deposits of gem tourmaline, beryl, and spodumene. **Dr. V. Bermanec** (University of Zagreb, Croatia) and colleagues studied dark blue, gem-quality apatite from Bahia, Brazil. The apatite samples are radioactive, due to the presence of uranium- and thorium-bearing oxides in microfractures. In separate presentations, **Dr. I. Haapala and S. Frindt** (University of Helsinki, Finland) provided new data on the evolution of the Gross- and Klein Spitzkoppe granitic intrusions in central Namibia. Gem-quality topaz and aquamarine formed in miarolitic cavities within the late-stage portions of the intrusions, which are characterized by pegmatite or greisen textures. **Dr. B. M. Shmakin** (Institute of Geochemistry, Irkutsk, Russia) proposed that rare minerals (e.g., of arsenic, bismuth, and antimony) found in several types of granitic pegmatites result from extreme concentration of certain elements during closed-system crystallization—that is, while isolated from chemical exchange with host rocks and the surrounding pegmatite.

ANNOUNCEMENTS

Yearly updates to the G&G “Twenty Year” Index. The online author and subject indexes (<http://www.gia.edu/gandg/indices.cfm>), which start with Spring 1981, have now been updated to include items from the 2001 issues of *Gems & Gemology*. Future online updates of the index are planned for the first quarter of each year.

Visit *Gems & Gemology* in Tucson. Meet the editors and take advantage of special offers on subscriptions and back issues at the G&G booth in the Galleria section (middle floor) of the Tucson Convention Center during the AGTA show February 5–10, 2003, and at the Tucson Gem & Mineral Society (TGMS) show February 13–16. A limited number of recently acquired out-of-print issues will also be available. For more information, contact subscriptions manager Debbie Ortiz at dortiz@gia.edu.

GIA Education’s traveling Extension classes will offer hands-on training in Tucson with *Gem Identification* (February 3–7) and *Advanced Gemology* (February 8). To enroll, call 800-421-7250, ext. 4001. Outside the U.S. and Canada, call 760-603-4001. GIA will also present two free seminars on February 9, *Business for Jewelers* and a *GIA Research Update*.

The GIA Alumni Association will host a Dance Party in Tucson on February 7, featuring a silent auction, an industry awards presentation, and a live auction. Included in the live auction will be a poster of the Spring 2002 cover of *G&G*, signed by Richard Liddicoat and a complete set of *Gems & Gemology* issues from 1981 to the present, donated by a former GIA employee. To reserve tickets, call 760-603-4204 or e-mail events@gia.edu.

The theme of this year’s TGMS show is “Gems and Minerals of the Andes Mountains,” which will be the topic of a one-day symposium on February 15. For more information, visit www.tgms.org.

New map of Russian gem resources. The Russian State Museum of Gems (also known as the Samotzveti Museum) in Moscow published a *Map of Deposits of Gemstones of Russia and Adjacent States 1:7,000,000* in 2000. The large (130 × 90 cm), full-color geologic map shows the locations for 130 gem and paleontological materials in the former Soviet Union. Accompanying the map is a 19-page booklet that contains explanatory notes and a

listing of the 380 deposits indicated on the map. The map is available for US\$50.00 by contacting the Museum's director, Dr. Anvar Yusipov, at samotzvety@mail.cnt.ru; fax 7-095-197-6763.

Conferences

Australian Diamond Conference. Scheduled to be held December 2–3, 2002 in Perth, Western Australia, this conference will include presentations by diamond producers and marketers in Australia and elsewhere. A pre-conference excursion (November 29–December 1) will visit the Argyle and Ellendale diamond mines. Contact Brooke Boardman at 61-8-9321-0355 (phone) or e-mail brooke@louthean.com.au.

ICA Congress. The 2003 International Colored Gemstone Association (ICA) Congress will occur in Jaipur, India, January 4–10, 2003. In addition to presentations and panel discussions on myriad colored stone topics, a tour of Sri Lankan gem mines has been organized for January 10–15. Visit www.icaindia.net.

Exhibits

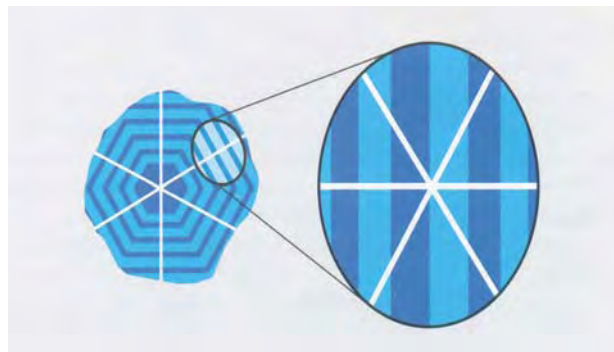
GIA Museum exhibits in Carlsbad. "Best of the Best," an exhibition of award-winning jewelry from industry association competitions, will be displayed in the Rotunda Gallery November 10, 2002, through May 2003. Winning pieces from the AGTA-sponsored Spectrum and Cutting Edge Awards, as well as the Diamond Information Center-sponsored Diamonds Today and Diamonds of Distinction awards, will be among those on exhibit. For further information, contact Alexander Angelle at 800-421-7250, ext. 4112 (or 760-603-4112), or e-mail alex.angelle@gia.edu.

Events at the Carnegie Museum of Natural History. On November 22–24, 2002, the fifth annual Carnegie Gem & Mineral Show will be held at this museum in Pittsburgh, Pennsylvania; it will include a special emerald exhibit from the Houston Museum of Natural Science. In addition, the exhibition *Fascinating Fakes* will run through December 8, 2002; it features nearly 20 examples of mineral specimens that have been altered to deceive the buyer and thus increase their apparent value. This exhibit is free with museum admission; call 412-622-3131, or visit www.carnegiemuseums.org/cmnh.

Gems at the Bowers Museum extended. "Gems! The Art and Nature of Precious Stones" (announced in Winter 2001 *Gems & Gemology*, p. 342) has been held over until January 5, 2003. Visit www.bowers.org or call 714-567-3600.

ERRATA

1. In the Winter 2001 Lab Note "Sapphires with Diffusion-Induced Stars" (pp. 324–325), the orientation of the stars to the color banding was incorrectly described in the text, as well as in the drawing of figure 21. On p. 325, the second sentence in the main paragraph in the center column should read (changes in italics): "Because color zoning is also related to the hexagonal crystal structure, the rays of *rutile-caused stars are most commonly perpendicular* to the six sides of the hexagon created by the growth/color zoning (see figure 21); *if the stars are created by ilmenite or hematite platelets, the rays point to the corners of the hexagon and are parallel to the color banding.*" The next sentence should read: "For stars caused by rutile, even if only one section of zoning is visible (as seen in the smaller of the two cabochons) two of the star's six rays would still be *perpendicular* to the visible banding." The last sentence of the caption to figure 21 should read: "Note that two of the six rays of a rutile star are always *perpendicular* to the color zoning." A corrected version of figure 21 is shown below. *Gems & Gemology* thanks Dr. Karl Schmetzer for bringing this error to our attention.



2. In the Spring 2002 GNI entry on etch features in beryl and quartz (pp. 102–103), Falk Burger of Los Alamos, New Mexico should have been acknowledged as the lapidary who polished the pieces shown in figures 26 and 27. We apologize for this omission.
3. In figure 10 of the Summer 2002 article on garnets from Tranoroa, Madagascar, by K. Schmetzer et al. (p. 154), samples Y and Z were inadvertently transposed. The pyrope-spessartines are actually positioned, from left to right: Samples E (Tranoroa, Cr>V), X (Bekily, V>Cr), Z (Bekily, V>Cr), and Y (Bekily, V<Cr).

LETTER OF COMPLETION IS PRESENTED TO

 Robert T. Jeweler
 FOR PARTICIPATION IN THE

2002 GEMS & GEMOLOGY CHALLENGE WINNERS



This year, 255 dedicated readers participated in the 2002 GEMS & GEMOLOGY Challenge. Entries arrived from all corners of the world, as readers tested their knowledge on the questions listed in the Spring 2002 issue. Those who earned a score of 75% or better received a GIA Continuing Education Certificate recognizing their achievement. The participants who scored a perfect 100% are listed below. Congratulations!

AUSTRALIA *Berala, New South Wales:* Barbara Wodecki. *Coogee, Western Australia:* Helen Judith Haddy. *Maleny, Queensland:* Erwin Stadelmann. *Slacks Creek, Queensland:* Ken Hunter **BELGIUM** *Diegem:* Guy Lalous. *Diksmuide:* Honoré Loeters. *Hemiksem:* Daniel De Maeght. *Overijse:* Margrethe Gram-Jensen. *Ruiselede:* Lucette Nols **BRAZIL** *Rio de Janeiro:* Luiz Angelo. *São Paulo:* Ana Flavia Pantalena **CANADA** *Bobcaygeon, Ontario:* David R. Lindsay. *Calgary, Alberta:* Janusz J. Meier, Sharon L. Paige. *Etobicoke, Ontario:* David N. Carabott. *Kingston, Ontario:* Brian Randolph Smith. *Laval, Québec:* Monique Savard. *Montreal, Québec:* Marie-France Rosiak. *St. Catharines, Ontario:* Alice J. Christianson. *Toronto, Ontario:* Ken Miller, David Reuben. *Vancouver, British Columbia:* Michael Cavanagh, Eva B. Nilsson. *Winnipeg, Manitoba:* Alyson Raynard **ENGLAND** *London:* Rosemary Ross. *Tenterden, Kent:* Linda Bateley **FINLAND** *Oulu:* Petri Tuovinen **FRANCE** *Paris:* Marie-France Chateau **GERMANY** *Nurnberg:* Herbig Klaus **INDIA** *Shimla:* Deepak Bagai **INDONESIA** *Jakarta:* Warli Latumena **ITALY** *Ferrara:* Sonia Franzolin. *Malnate, Varese:* Tralli Gabriele. *Porto Azzurro, Livorno:* Diego Giuseppe Trainini. *Valenza:* Rossella Conti. *Vicenza:* Fabio D'Amico, Francesca Zen **NETHERLANDS** *Rotterdam:* E. van Velzen. *Wassenaar:* Jane M. Orsak **PARAGUAY** *Asunción:* Viviana Stiegwardt **PORTUGAL** *Figueira, Algarve:* Johanne Jack **SCOTLAND** *Edinburgh:* James Heatlie **SPAIN** *Playa P. Farnals, Valencia:* Monika Bergel Becker. *Madrid:* Shahrazad Krewi de Urquijo **SWEDEN** *Järfälla:* Thomas Larsson **SWITZERLAND** *Rodersdorf:* Heinz Kniess. *Zollikon:* Adrian Meister. *Zürich:* Eva Mettler **THAILAND** *Bangkok:* Zin Win Mon **ZIMBABWE** *Harare:* Lesley Faye Marsh **UNITED STATES** **Arizona** *Sun City:* Anita R. Wilde. *Tucson:* Dave Arens, Luella Dykhuis, Molly K. Knox. **California** *Burlingame:* Sandra MacKenzie-Graham. *Burney:* Willard C. Brown. *Carlsbad:* Michael T. Evans, Elaine Ferrari-Santhon, Brian Genstel, Martin Harmon, Alethea Inns, Mark Johnson, Doug Kennedy, Jan Lombardi, Roxana J. Lucas, Diane Saito, Abba Steinfeld, Jim Viall, Michael Wobby, Philip G. York, Marisa Zachovay. *Coronado:* Allen P. Salgado. *Fremont:* Ying Ying Chow. *Hercules:* Ana Tom. *Los Angeles:* Veronica Clark-Hudson. *Los Gatos:* G. Donald Eberlein. *Marina Del Rey:* Veronika Riedel. *Mill Valley:* Susan Bickford. *Rancho Cucamonga:* Sandy MacLeane. *Redwood City:* Starla Turner. *San Diego:* Joseph St. Eliyas. *San Jose:* Wendy Bilodeau. *San Rafael:* Robert A. Seltzer. *Seal Beach:* Barr L. Doty. **Colorado** *Aurora:* Ronda Gunnett. *Colorado Springs:* Barbara J. Maffei. *Denver:* Mary Shore. **Connecticut** *New Haven:* Matilde McAfee. *Vernon:* Joe Thon. **Florida** *Clearwater:* Timothy D. Schuler. *Coral Gables:* D. Christine Lones. *DeLand:* Sue Angevine Guess. *Lauderdale-by-the-Sea:* Pamela J. Rossi. *Palm Coast:* Donald Haren. *Satellite Beach:* Consuelo Schnaderbeck. *Sun City Center:* Jeanne Naish. *Sunrise:* Timothy J. Swygard. *Tampa:* Kirsten Becker, R. Fred Ingram. **Georgia** *Woodstock:* H. Regenia Staley. **Hawaii** *Hanalei:* Nancy Y. Blanton. *Honolulu:* Brenda Reichel. *Makawao:* Alison Fahland. **Illinois** *Chicago:* Linda Nerad. *Danvers:* Anne Blumer, William Duff. *Elgin:* Jerry Long. *Mokena:* Marianne Vander Zanden. **Indiana** *Fishers:* Laura D. Haas. *Indianapolis:* Mark Ferreira. **Kentucky** *Shepherdsville:* Carroll J. Kiefer. **Maine** *South Freeport:* Arthur E. Spellissy Jr. **Maryland** *Baltimore:* Alissa Leverock. *Darnestown:* Ron Suddendorf. *Patuxent River:* Pamela D. Stair. **Massachusetts** *Braintree:* Alan R. Howarth. *Brookline:* Martin Haske. *Lynnfield:* John A. Caruso. *Uxbridge:* Bernard M. Stachura. **Minnesota** *Paw Paw:* Ellen Fillingham. *Rochester:* Renato V. Rossi. **Missouri** *Perry:* Bruce L. Elmer. **Mississippi** *Hattiesburg:* A. Thomas Light. **North Carolina** *Advance:* Blair Tredwell. *Candler:* Christian Scott Richart. *Creedmoor:* Jennifer Jeffreys-Chen. *Greensboro:* Lorraine D. Dodds. *Kernersville:* Jean A. Marr. *Manteo:* Eileen Alexanian. *Wilmington:* Ben H. Smith Jr. **New Jersey** *Union:* Thaïs Anne Lumppp. **New Mexico** *Albuquerque:* Mark Daniel West. **Nevada** *Las Vegas:* Deborah A. Helbling. *Reno:* Terence E. Terras. **New York** *New York:* Armando Aranjó, Dan Campbell, Fran Greder, Anna Schumate. **Ohio** *Cuyahoga Falls:* Catherine S. Lee. *Dayton:* Michael Williams. *Powell:* Benjamin T. Stahl. **Oregon** *Hermiston:* Thelma Roe. *Medford:* Barbara A. Johnson. **Pennsylvania** *Jonestown:* Edward E. Reichard. *Schuylkill Haven:* Janet L. Steinmetz. *Yardley:* Jon Barry DiNola, Peter R. Stadelmeier. **South Carolina** *Sumter:* James S. Markides. **Tennessee** *Germantown:* Charles L. Rose. **Texas** *Corpus Christi:* Warren A. Rees. *Flower Mound:* Elizabeth M. Roach. *Houston:* Karen L. Jensen. *Katy:* Christine Schnaderbeck. *San Angelo:* Henry R. Chipman. **Virginia** *Kilmarnock:* Mary K. Helne. **Washington** *Poulsbo:* Ruth Jorgensen. *Redmond:* Andrea Frabotta. *Seattle:* Janet S. Holmes, Ahmad Samsavar. *Spokane:* Jan Jennings. **Wisconsin** *Beaver Dam:* Thomas G. Wendt. *East Troy:* William Bailey. *Mequon:* Kathleen J. Molter



Answers (See pp. 109–110 of the Spring 2002 issue for the questions): (1) c, (2) b, (3) a, (4) b, (5) a, (6) c, (7) b, (8) a, (9) d, (10) c, (11) b, (12) d, (13) c, (14) b, (15) c, (16) d, (17) c, (18) b, (19) c, (20) b, (21) b, (22) c, (23) withdrawn, (24) a, (25) d

EDITORS

Susan B. Johnson
Jana E. Miyahira-Smith

From Mine to Mistress: Corporate Strategies and Government Policies in the International Diamond Industry

*By Chaim Even-Zohar, 555 pp.,
publ. by Mining Journal Books Ltd.,
Edenbridge, England. US\$495.00*

More and more, governments and corporations around the world are focusing on the diamond industry, for a whole host of reasons: New deposits are being discovered in places not traditionally associated with diamond production, demand for diamonds is growing, and unscrupulous people have been using them as a form of international currency.

The author, who has worked in the industry for 30 years, produced this book as a "one-stop" reference to guide policymakers and corporate executives who have little previous knowledge of the industry through what appears to be a mysterious, jumbled process. This helps explain the price of this volume.

The book is divided into four main sections. The first offers an extensive overview of the workings of the diamond pipeline. It begins with an account of the development of the diamond industry in the 18th and 19th centuries, including government attempts to control new discoveries in Brazil and South Africa. It then traces the rise of De Beers and its struggle to contain and control diamond production during World War II, which led to the U.S. Justice Department's long-running anti-trust action. The subsections that follow provide a general look at how the industry is organized, how De Beers and others market rough diamonds, the economics of each stage of

the diamond pipeline, and the role of De Beers's Diamond Trading Company and others in controlling prices. The section concludes with a lengthy *realpolitik* look at the conflict diamond issue.

The second section is devoted to diamond producers. It opens with an overview of world diamond production, and then offers an in-depth analysis of the political and economic forces that affect diamond mining in each producing country. In Botswana, for example, the author examines the partnership between the government and De Beers, and looks into the controversial practice of setting up local diamond polishing operations to boost employment. The government wants such operations to add value to its diamonds, while De Beers argues that such facilities are too far removed from the mainstream to market their polished goods profitably.

Some nonproducing countries play a vital downstream role in the diamond industry. The third section examines the forces that impact the major diamond-processing centers (labor costs, government policies and assistance to polishing firms, and productivity and banking issues). As with the producers, the author examines each country in turn, assessing strengths and weaknesses and offering an outlook for the future.

The final section considers global issues that affect the diamond trade: political and legal restraints (such as the De Beers anti-trust case); the branding revolution that has brought new marketing initiatives and diamond cuts to the trade; and the complicated world of diamond financing.

Appendices offer documents, such as the official framework for dia-

mond origin certification drawn up by the Kimberley Process, and glossaries of specialized terms dealing with key issues affecting the trade today.

Some of the information published in this book has appeared piecemeal in the author's and other trade publications, but much of it is new. Moreover, all of the information is presented with a greater depth and understanding than any other source currently available. While there is some redundancy of topics between sections, the information is generally concise, well-organized, and very easy to access.

Beyond the wealth of information it contains, the book's greatest asset is its apparent objectivity. Today, as governments attempt to deal with conflict diamonds, fiscal matters affecting the industry (such as the Patriot Act), and a burgeoning trade, numerous groups are offering policy advice tailored to furthering their own agendas and viewpoints. Until this book was completed, there was little objective information to guide policymakers.

The price will, of course, deter the casual browser and the hobbyist. However, this book is a "must have" for any organization, government, or corporation that has a stake in the diamond industry.

RUSSELL SHOR

*Gemological Institute of America
Carlsbad, California*

**This book is available for purchase through the GIA Bookstore, 5345 Armada Drive, Carlsbad, CA 92008. Telephone: (800) 421-7250, ext. 4200; outside the U.S. (760) 603-4200. Fax: (760) 603-4266.*

Light & Stone: Highlights from the Scott Gem Collection

Photography by Harold and Erica Van Pelt, commentary by Peter C. Keller and Michael M. Scott, publ. by the Bowers Museum of Cultural Art, Santa Ana, California, 2002. US\$25.00 (softbound)*

This new book offers highlights of an extraordinary collection, that of Michael M. Scott, past president of Apple Computer, Inc. Noted gemologist and author Peter C. Keller calls it "arguably the most important gem collection in the United States." In the foreword, Keller enthuses about the diversity of gems, gem artistry, and minerals. The highlights of the book are breathtaking, encompassing fancy-color and colorless diamonds, as well as important colored gems. Among the treasures: a 400 ct faceted golden sapphire, a heart-stopping 1,730 ct ruby crystal from Mogok, and a 242 ct faceted tanzanite (perhaps the largest ever cut). Glyptic arts and metalsmithing are also celebrated. The last section features the works of Seattle-based silversmith John Marshall, as well as noted Idar-Oberstein sculptors Gunter Petry, Gerd Dreher, and Bernd Munsteiner.

The Scott collection is brought to light through the eyes, lenses, and photographic expertise of Harold and Erica Van Pelt, the world-renowned husband-and-wife team of gem and mineral photographers. Their genius graces almost every page, not only recording the beauty of the specimens, but also interpreting them in such a way that defines how the pieces *should* be looked at. Bravo! The book exhibits the treasures well, too, with its oversize (10 × 14 inch) format, which lends itself to the stunning use of more than 70 Van Pelt images, many of them occupying a full page or two-page spreads.

Mr. Scott dedicates a page of the book to addressing would-be gem and mineral collectors, advising them on how to build a collection by starting with small specimens, and focusing on a single species or even a particu-

lar shape within that species. "My goal has been to collect quality and beauty . . . and for the collection to tell the emotional story of the impact of colors," he writes. Readers of this book will readily see that this goal has been largely accomplished.

The book covers many of the main gem species and varieties, though there are some notable exceptions. For example, spinel, chrysoberyl, feldspars, and pearls are absent (except as side stones). Nor does the book include many ornamental gems, such as jadeite or lapis lazuli. This suggests the possibility that Mr. Scott has not yet reached his goals with regard to those gems, or that a sequel is planned. Finally, it is hard to know whether the book is considered a text or a partial catalogue. While there is a quasi-table of contents, there are no page numbers to which it can refer. An index to the various gem materials and artists represented also would have been a nice addition.

For those lucky enough to peruse the book, those points are minor details. After examining the cover and turning a few pages, the viewer will be lost in the scope of the collection, the beauty of the photography, and the technical perfection of the jewelry and glyptic arts.

ROBERT WELDON, G.G.
Professional Jeweler *Magazine*
Philadelphia, Pennsylvania

Gemstones Quality and Value, Volume 2

*By Yasukazu Suwa, 144 pp., illus., publ. by Sekai Bunka Publishing Inc., Tokyo, (2nd ed., English translation) 2002. US\$95.00**

How much time, money, and effort would it take to "learn the colored stone business"? You would need to be able to recognize the different qualities in which the various gems occur, how they vary in price, and the relative rarity of different sizes and colors. You would also need to keep copious notes, and color-reference photographs would be invaluable. In this one book,

the author offers an excellent reference for such information on 22 of the more important gem materials and four cuts/shapes of diamond. It is information that normally would be difficult, expensive, and time consuming to acquire.

The book features four-page entries on cat's-eye chrysoberyl; citrine; fancy blue, pink, and yellow diamonds; Zambian emerald; iolite; boulder and Mexican opal; Mogok, Mong-Hsu, and star ruby; fancy-color, Sri Lankan, and star sapphire; red spinel; tsavorite; Imperial topaz; bicolored tourmaline; blue zircon; amber; pink coral; and emerald-cut, marquise-cut, pear, and princess-cut diamonds. For most of these items, there is a Quality Scale grid with five "beauty" grades and seven tones on the two axes. Numerous color illustrations of representative gems are provided for these grids. In most cases, these are the best visual representations of gemstone quality ranges I have ever seen. An additional chart shows which of these examples fall within one of three grades: gem quality, jewelry quality, or accessory quality. Also discussed are how prices vary between particular weights or grades. Where appropriate for a specific gem material, the subjects of treatment and origin are covered in a clear and conscientious manner.

A chapter on value covers the impact of factors such as country of origin, treatments, beauty, tone, defects, and size on the value of a gem. Value comparison charts are provided for 42 gem materials, including gems featured in Volume 1. They show relative values for the three quality ranges and three carat weights, but they are not meant to be used as a price list.

The color printing is excellent, and the scope and depth of material covered is amazing. Nothing can replace trade experience, but I believe this book would benefit anyone in the gem and jewelry business.

DOUGLAS KENNEDY
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Murzinka: Alabashka Pegmatite Field

By Valentina I. Popova, Vladimir A. Popov, and Alexander A. Kanonerov, illus., 136 pp., Vol. 5 of the *Mineralogical Almanac series*, publ. by Ocean Pictures Ltd., Russia, 2002. US\$39.95 (softbound)

The Murzinka mining region in the Ural Mountains of Russia is best known for its production of fine mineral specimens, including beryl and topaz. Historically, specimens from the region have been labeled simply "Murzinka," even though the most important mines are located in the Alabashka field of granitic pegmatites. This book, Volume 5 of *Mineralogical Almanac*, surpasses its predecessors with a complete and updated description of the Alabashka pegmatites. Matching the superb photography and print quality is detailed content written by dedicated experts in the field.

The Introduction provides a brief overview of the region, with maps showing the locations of mines and a table that covers 12 of the Alabashka veins and the minerals they have yielded. Chapter 2 provides an excellent summary of past and recent exploration and mining activities. From the well-chosen citations, it is clear that the authors have spent considerable time searching the literature, especially old archives. The next chapter offers a brief but excellent geologic review, including a simplified geologic map of the region. This is followed by an up-to-date presentation on eight of the most important granitic pegmatites of the Alabashka field.

The fifth and final chapter, Mineralogy, is the most extensive. It is richly illustrated with photos of beautiful crystals, showing a selection of the various morphologies, etched crystals, and somewhat rare species. Each mineral species is thoroughly analyzed as to occurrence, size, and paragenesis. (The authors have made a major effort to describe crystal forms of topaz.)

The book concludes with a Russian-to-English glossary of words related to Alabashka and a references section. The book would have benefited from some additional references, as well as production figures. Aside from these items and a few minor mistakes in the text, it is difficult to find fault with this publication.

In short, this is an excellent volume, the best ever written on the Alabashka pegmatite field. It is highly recommended for anyone interested in mineralogy or geology, and it is an absolute must for anyone seriously interested in classical deposits, Russian mineralogy, or pegmatites.

PETER LYCKBERG
Sweden/Luxembourg

Gemstones and Other Unique Minerals and Rocks of Wyoming: A Field Guide for Collectors

By W. Dan Hausel and Wayne M. Sutherland, illus., 268 pp., *Bulletin 71, Wyoming State Geological Survey, Laramie, 2000*. US\$20.00 (softbound)

This book is intended as a guide to the gem minerals and related rock occurrences in Wyoming for the gemologist, mineral collector, or rock hound who has some mineralogy and geology background.

The book covers 38 general materials, many of which are broken into more specific categories. For instance, the heading "Ore Minerals" actually comprises 45 different minerals, and "Quartz" covers both crystalline and cryptocrystalline varieties, which this state has in abundance. Most of the general headings include numerous localities, probably more than could be explored in many years.

The book is rich in useful professional maps, rather than the hand-drawn kind found in so many other field guides. (Where a map is not supplied, the appropriate U.S. Geological Survey topographic map or geologic map is recommended for the given occurrences.) As a textbook on miner-

als and gems, however, it is somewhat lacking. The ore minerals are given only brief descriptions; yet, oddly, the statement that certain copper ores "will partially replace a weathered rock hammer with native copper when the hammer is rubbed into the mineral wetted with dilute hydrochloric acid" is made four times. Some of the gemological descriptions contain outdated information, or in some instances are simply in error. For example, in one case the authors cite as a reference two classic works by Max Bauer that were translated into English in the early 20th century. Such early works describe gems that are highly valued by today's standards—such as alexandrite, black opal, and demantoid garnet—as merely "semi-precious." Also, even though the authors correctly state that there is no jadeite jade in Wyoming, they claim that "Imperial" jade (a trade designation for the finest green jadeite) has been found there. Other examples include: The pyro- and piezoelectric properties of tourmaline are attributed to topaz; quartz crystals are reported to be terminated by a pyramid or bipyramids (quartz actually is terminated by two rhombohedra); and iolite is wrongly reported to be uniaxial rather than biaxial.

In addition, table 3 lists some gem-quality diamonds collected from the Wyoming side of the State Line district. It is not clear if the information given is for rough specimens or fashioned gems. The grading terms, taken from Bruton (1976) do not exactly correlate to the GIA system; for instance, VVS is defined as top grade, flawless.

Gemstones of Wyoming does a good job at its primary purpose, that is, to list and locate the gem materials that can be found in that state. However, it is less reliable as a description of the materials themselves. Nevertheless, for those who want to do some serious collecting in the Cowboy State, this is the book to use.

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COLORED STONES AND ORGANIC MATERIALS

Characterization of beryl (aquamarine variety) by Mössbauer spectroscopy. R. R. Viana, G. M. da Costa, E. De Grave, H. Jordt-Evangelista, and W. B. Stern, *Physics and Chemistry of Minerals*, Vol. 29, No. 1, 2002, pp. 78–86.

Five aquamarine samples were analyzed by Mössbauer spectroscopy to find a correlation between their dark blue to greenish blue colors and the locations of iron atoms in the beryl structure. An asymmetric Fe^{2+} doublet was observed in the spectra of all samples at room temperature. The asymmetry is related to a relaxation process involving Fe^{2+} ions and water molecules in structural channels. At higher temperatures, the spectra indicated at least two Fe^{2+} components. At very low temperatures, the spectra of a deep blue specimen showed that Fe^{2+} was in structural channels. Fe^{2+} also occupied octahedral and tetrahedral sites, whereas Fe^{3+} was only located in the octahedral site. The authors conclude that the color of green-to-blue beryls is determined by the relative proportions of Fe^{3+} in the octahedral sites and of Fe^{2+} in the channels. Thus, deep blue beryls have little Fe^{3+} , whereas greener beryls have more octahedral Fe^{3+} or less channel Fe^{2+} . *AI*

The enhancement techniques of pearls. G. Shouguo and S. Lingyum, *Journal of the Gemmological Association of Hong Kong*, Vol. 22, 2001, pp. 32–36.

This article gives a short but very informative overview of several techniques used to enhance the appearance and value of Chinese freshwater and saltwater cultured pearls. Details are given of the procedures used for dyeing, bleaching, polishing, and adding luster to cultured pearls by immersing them in chemicals.

This section is designed to provide as complete a record as practical of the recent literature on gems and gemology. Articles are selected for abstracting solely at the discretion of the section editor and his reviewers, and space limitations may require that we include only those articles that we feel will be of greatest interest to our readership.

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Of particular interest are the many chemical formulations and "recipes" for cultured pearl enhancement, as well as the temperatures at which the enhancements are performed and the length of time they must remain in the various solutions. For example, one bleach solution is identified as hydrogen peroxide + chloroform + 3-ethanol-amine + 12-alkyl sodium sulfate + Britton-Robison buffer solvent. The concentration of hydrogen peroxide is usually 2%–4%, and the recommended bleaching temperature is 30°–35°C. The bleaching time for light-colored cultured pearls is two to three days, but at least 10 days are required for dark-colored varieties. Twelve illustrations complement the text and show how the pearls are harvested, sorted, and subjected to some of the treatments. *LT*

Five centuries of Mexican pearls. D. M. Moreno and E. A. Castillo, *Australian Gemmologist*, Vol. 21, No. 5, 2002, pp. 190–201.

The history of the Mexican pearl industry in the Gulf of California, on Mexico's Pacific Coast, is reviewed. Details are given of the development of the pearl-culturing industry responsible for creating the Sea of Cortez™ bead-nucleated cultured pearl. The history of cultured pearls worldwide is described, and the pervasive influence of the Japanese pearl-culturing industry is outlined. Innovative Mexican methods used to produce loose (whole) cultured pearls from the indigenous rainbow-lipped pearl oyster (*Pteria sterna*) are described, together with the unique features of the pearls cultured in this bivalve. The farming is claimed to have a positive environmental impact on the Gulf of California. *RAH*

Iridescence of a shell of the abalone *Haliotis rufescens* caused by diffraction. Y. Liu, K. N. Hurwit, and J. E. Shigley, *Journal of Gemmology*, Vol. 28, No. 1, 2002, pp. 1–5.

The strong iridescence observed in the shell of the abalone *Haliotis rufescens* is a result of the diffraction of light by microscopic aragonite tiles that are arranged in a statistically regular pattern. This specific tile structure serves as a two-dimensional reflection grating. However, the iridescence found in bivalve mollusk shells (e.g., from mussels and oysters) results from a finer-scale micro-groove structure that serves as a single reflection grating. The iridescence caused by this structure in bivalve shells is directional and cannot be observed along the groove direction, whereas that from the two-dimensional structure can be observed in any direction. This difference partially explains the more subtle colors observed in bivalve shells compared to the brilliant hues seen in abalone shell. *JEC*

Lapis lazuli—Eigenschaften und Vorkommen, Imitationen und künstliche Eigenschaftsveränderungen [Lapis lazuli—Properties and occurrences, imitations and treatments]. U. Henn and C. Braun, *Gemmologie: Zeitschrift der Deutschen Gemmologischen Gesell-*

schaft, Vol. 50, No. 2, 2001, pp. 95–108 [in German with English abstract].

Lapis lazuli, one of the oldest gem materials used in jewelry, is revered for its deep blue color. It is an aggregate (a rock) mainly composed of lazurite, but additional minerals such as diopside, calcite, and pyrite are usually present. Commercially important mines are located in Afghanistan, Chile, and Russia. Because lapis lazuli is such an important gem, it has several imitations, both natural (e.g., sodalite) and man-made (e.g., "Gilson synthetic lapis" and certain ceramic materials). Some of the imitations cannot be distinguished from the natural material by macroscopic appearance alone. This article summarizes the distinguishing properties of natural lapis lazuli and its imitations.

When unset, natural lapis lazuli may be identified by refractive index and/or specific gravity measurements, followed by a microscopic study. When set in jewelry or fashioned as an *objet d'art*, a sample must undergo additional or advanced testing, such as infrared spectroscopy.

Claudia S. D'Andrea

DIAMONDS

Growth habit of needle crystals in coats of coated diamonds. N. Shimobayashi and M. Kitamura, *Journal of Mineralogical and Petrological Sciences (Japan)*, Vol. 96, No. 5, 2001, pp. 188–196.

In coated diamonds from the Democratic Republic of Congo (Zaire), the coatings were found to consist of an aggregate of acicular diamond crystals over an octahedral single-crystal core. The tips of the acicular crystals in the coatings are bounded by curved {100} faces (or cuboids) with small {111} (octahedral) faces, showing a distinct sector zoning in cathodoluminescence brightness. This characteristic form of the acicular crystals is interpreted to be a result of the co-precipitation of inclusions, and of rapid growth controlled by kinetic roughening of the octahedral faces and kinetic smoothing of the cuboid faces. *RAH*

In praise of diamond fluorescence. R. B. Drucker, *Jewelers' Circular Keystone*, Vol. 173, No. 5, 2002, pp. 124–130.

Until 20 years ago, diamond fluorescence was regarded as an asset, in that it was the origin of the color term *blue-white*. Although this term was banned by the Federal Trade Commission in 1938, fluorescent diamonds still traded at a premium. That changed in the late 1970s, when buyers in the Far East began rejecting strongly fluorescent stones, especially in the top colors. Since then, fluorescent diamonds have traded at a discount, currently 3%–6% for the more strongly fluorescent blue varieties. A recent study (see Winter 1997 *Gems & Gemology*, pp. 244–259) noted fluorescence in 35% of diamonds. Of those that fluoresced, 62% were medium to very strong; and of those, 97% were blue.

This article emphasizes that blue fluorescence in a colorless diamond can, in many cases, make the diamond appear to be better in overall color appearance than it actually is. Therefore, the discount compared to nonfluorescent diamonds is unjustified (except in the case of "overblues" and stones with yellow fluorescence). The author believes that retailers have missed many opportunities to promote the positive aspects of diamond fluorescence and have lost sales because of negative or poor information about fluorescence. RS

Indicator mineral and geochemical methods for diamond exploration in glaciated terrain in Canada. M. B. McClenaghan and B. A. Kjarsgaard. In M. B. McClenaghan et al., Eds., *Drift Exploration in Glaciated Terrain*, Geological Society of London, Special Publication No. 185, 2001, pp. 83–123.

Kimberlites are the primary focus of diamond exploration in Canada, but the search for these rocks is complicated by the effects of glaciation. Glaciers have eroded kimberlite pipes and obscured their presence with the deposition of glacial drift. This article summarizes the current exploration techniques in glaciated areas, which are based primarily on diamond indicator minerals and till geochemistry.

Kimberlites are mineralogically and chemically distinct point sources that may yield distinctive indicator-mineral (mainly pyrope, Mg-ilmenite, Cr-diopside, and Cr-spinel) dispersion trains, or chemical-element (e.g., Ni, Cr, Ba, Co, Sr, Rb, Nb) signatures in glacial tills. Indicator minerals may be traced for long distances (up to several hundred kilometers) to their potentially diamond-bearing source. Similarly, chemical analysis of tills may be effective, especially if there is a good contrast in the abundance of pathfinder elements between the till and surrounding rock masses. With both exploration methods, an understanding of ice flow history in the area is essential. The till-geochemistry technique is gaining popularity, because it is significantly cheaper than indicator-mineral analysis and can be performed quickly. Numerous examples are given of recent successes using both techniques in various parts of Canada. AAL

GEM LOCALITIES

After the fall. G. Austin, *Colored Stone*, Vol. 15, No. 2, 2002, pp. 34–35.

Since the 1865 discovery of alluvial sapphires in western Montana, numerous attempts have been made to exploit them. American Gem Corporation (AGC), which went public in 1994, experienced the most recent, and perhaps the most spectacular, failure because of low sales and high operating costs. In early 2001, Digital Gem Corp. (the post-1999 name of AGC) sold its remaining inventory of 6–8 million carats of rough sapphires, along with an undisclosed amount of cut sapphires and jewelry inventory, to

Fine Gems International (FGI) of Helena, Montana. Other assets of the original AGC operations (e.g., the heat treating facilities, and the mine and processing facilities at Rock Creek) were sold separately to others.

FGI, which has a large stock of precision-cut, calibrated sapphires mostly in the 2–5 mm size categories, hopes to finally bring Montana sapphires to the mainstream market by developing new lines with manufacturers and designers. Among those is gem cutter Glenn Lehrer, designer of the Torus Ring™ cut (a carved doughnut shape), who is selling Torus Ring-cut sapphires through Stuller Inc., a volume jewelry supplier. MT

Compositions and formation conditions of fluid inclusions in emerald from the Maria deposit (Mozambique). Y. Vapnik and I. Moroz, *Mineralogical Magazine*, Vol. 66, No. 1, 2002, pp. 201–213.

Fluid inclusions in emerald and quartz from the Maria hydrothermal vein deposit, which cuts Precambrian ultrabasic rocks, were studied using microthermometric and Raman microprobe techniques. Inclusions in the emeralds contained fluids in the Na–Ca–Mg–(HCO₃)⁻–(CO₃)⁻–Cl–H₂O system that were saturated in carbonic acid brines. Nahcolite (NaHCO₃) was the main daughter phase; other daughter minerals included Mg-calcite, magnesite, calcite, and aragonite. Zones of fluid inclusions with numerous birefringent solid phases were typical of emeralds from the Maria deposit. The probable conditions of emerald growth are 400°–500°C at 3–5 kbar. RAH

Corundum/spinel reaction textures in carbonate-origin rocks, Sri Lanka. M. D. P. L. Francis and P. G. R. Dharmaratne, *Australian Gemmologist*, Vol. 21, No. 5, 2002, pp. 211–214.

Crystals of corundum with a spinel crust are common in marble of the Highland Complex in central Sri Lanka. The authors suggest that the spinel was formed by a reaction between phlogopite and corundum to give spinel and K-feldspar. A complete transformation is illustrated between hexagonal crystals of corundum and the development of an irregular spinel rim, eventually leaving a ragged core of corundum and finally yielding a crystal of spinel. RAH

Cuprian elbaite from the Batalha mine, Paraíba, Brazil. W. E. Wilson, *Mineralogical Record*, Vol. 33, March–April 2002, pp. 127–137.

Cuprian elbaite, known in the gem trade as "Paraíba" tourmaline, was discovered in pegmatite veins at the Batalha mine in northeastern Brazil in 1988. The presence of relatively high concentrations of copper (up to 2.3 wt.% CuO), and to a lesser degree manganese, results in a range of extraordinary colors. Particularly prized are the unusually bright and rich "turquoise"-blue specimens. Heat treatment is commonly used to enhance the color of as-mined material. Most crystals recovered are shattered and/or

heavily etched, and thus of poor gem quality. Nearly all good crystals are small (1–3 cm in size), but few survive for mineral collectors due to the high market value for the faceted stones (\$20,000 per carat in some cases). *CT*

Found in the Guatemalan wilds, jade lode as big as Rhode Island. W. J. Broad, *New York Times*, May 22, 2002, pp. A1, A10.

The first significant modern discovery of the source of jadeite used by pre-Columbian and more recent civilizations (e.g., Olmec, Mayan, Aztec) in Mesoamerica was made in 1974 in Guatemala's Motagua River valley [see Summer 1990 *Gems & Gemology*, pp. 134–141]. However, most of this material is opaque and dull colored, and does not resemble the translucent and colorful "Olmec" blue and blue-green jadeite found in many carved jadeite artifacts produced by the ancient civilizations.

Recently, an important *in situ* deposit of remarkably translucent blue and blue-green jadeite was found that resembles the jadeite used in ancient times. The occurrence is in a mountainous region, approximately the size of Rhode Island, which straddles the Motagua River. The discovery is, in part, a result of the devastating floods of 1998, which caused landslides that exposed old veins and washed jadeite boulders (some of which are described as "bus-sized") into river beds. *AAL*

Jeremejevite from Namibia. W. E. Wilson, C. L. Johnston, and E. R. Swoboda, *Mineralogical Record*, Vol. 33, No. 4, 2002, pp. 289–301.

In 1973, jeremejevite was discovered in pegmatites at "Mile 72" (also known as the Cape Cross locality), north of Swakopmund, Namibia. This article relates details of the discovery, presents mineralogical and gemological properties of the jeremejevite, and describes initial mining activities from 1973 to 1976. A small number of crystals were recovered, ranging from colorless to "cornflower" blue; some were acquired by major museums (e.g., the Smithsonian Institution). In 1999, a new consortium mined the deposit using modern equipment, but they recovered only ~300 crystals, mostly colorless to yellow. The area has since been backfilled according to reclamation requirements.

More recently (since March 2001), fine, lustrous crystals of jeremejevite have been recovered from pegmatites in the Erongo Mountains [about 180 km east of Mile 72; see GNI entry in this issue]. Mining there has been hindered by restricted access and lack of water. *MT*

Les nouvelles mines de La Pita (Colombie), 1ère partie [The new mines of La Pita (Colombia), part 1]. J.-C. Michelou, *Revue de Gemmologie*, No. 143, 2001, pp. 9–13. **Les nouvelles mines d'émeraude de La Pita (Colombie), 2e partie [The new emerald mines of La Pita (Colombia), part 2].** E. Fritsch, B. Rondeau, F. Notari, J.-C. Michelou, B. Devouard, J.-J. Peucat, J.-P.

Chalain, Y. Lulzac, D. de Narvaez, and C. Arboleda, *Revue de Gemmologie*, No. 144, 2002, pp. 13–21 [in French with English abstract].

These two articles are part of a series on the emeralds of Colombia. Part 1 describes the history and geology of the La Pita mines, which are situated between Muzo and Coscuez. From rather modest beginnings in the 19th century and frequent changes of ownership, La Pita has become the most important source of emeralds in Colombia. Since May 1999, it has accounted for about 65% of the country's emerald production.

Part 2 describes the geology and mineralogy of La Pita in more detail—not surprisingly, both are very similar to what is seen at Muzo and Coscuez—and concentrates on the gemological properties of the emeralds. Crystals can be as large as 10 cm (4 inches); generally, they are prismatic with a wide range of minor prism and pyramidal faces, sometimes in combinations that are characteristic for the occurrence. The specific gravity, optical properties, and inclusions are typical for Colombian emeralds. Although the overall chemical composition also is consistent with Colombian emeralds, the marked predominance of V over Cr together with very low Rb contents and typical Mg values appear to be characteristic of La Pita emeralds. *RT*

Madagascar. A Mineral and Gemstone Paradise. *extraLapis English*, No. 1, 2001.

The popular German *extraLapis* series now has an American counterpart, *extraLapis English*. The first publication in this new series is an English translation (with updated text) of the 1999 Madagascar issue (No. 17) that was written by Federico Pezzotta.

The issue starts with an historic overview beginning with the settlement of Madagascar by 18 ethnic groups who migrated from Malaysia and Indonesia about 2,000 years ago. Following an eventful history, in 1960 the island peacefully transformed from a French colony to an independent republic. Although a traveler named Flancourt mentioned the occurrence of various gems on the island in 1658, systematic mineral exploration and organized mining started only in the 20th century. The breakthrough is marked by Alfred Lacroix's classic 1912 treatise on the mineralogy of Madagascar. Since then, however, gem mining and trading in this country have been challenged by poor infrastructure and at times political instability.

The bulk of the issue is dedicated to a discussion of the geology and mineralogy of Madagascar, and the enumeration and description of important deposits and their minerals. Along with skarns, which contain important ore deposits (gold) and corundum occurrences, Madagascar is famous for its pegmatites and alpine veins, which are the sources of a wide range of gem minerals (including rare gem classics such as liddicoatite, yellow orthoclase, sphene, and rhodizite-londonite). The volume ends with a description of the hydrothermal deposits of quartz varieties (including amethyst scepters, rock crystal, and star rose

quartz), and of ancient sediments that contain not only the famous blue celestite geodes, but also important gem-bearing placer deposits (e.g., Ilakaka). The issue is lavishly illustrated, like its German counterpart, and includes geologic and location maps of the pegmatite districts, along with lists of minerals and mineral occurrences. *RT*

Emeralds of the World. *extraLapis English*, No. 2, 2002.

This second issue in the *extraLapis English* series is a translation of the recent emerald issue (No. 21, 2001) of the German *extraLapis* series [see Summer 2002 Gemological Abstracts, p. 194], and was edited by the late John Sinkankas. With the interests of a wider international audience in mind, some changes have been made. Noteworthy are the addition of: (1) an article on North Carolina emeralds (by M. Wise); (2) another perspective (by L. Conklin) on the problem of defining the term *emerald* (to accompany the original article on this subject by D. Schwarz and K. Schmetzer); and (3) a discussion of "The Four R's of Mineral Specimen Enhancement" (Reinforcement, Repair, Restoration, and Reconstruction) by M. L. Wilson. *RT*

Piteiras, Brasilien: Erfolgreiche Smaragdsuche mit modernsten Methoden (Piteiras, Brazil: Successful emerald prospecting with state-of-the-art methods). J. Kanis, *Lapis*, Vol. 27, No. 3, 2002, pp. 13–18 and 50 [in German].

The Piteiras property may become an important source of emerald in Brazil, yielding both cabochon and fine-quality facetable material. Unlike other gem occurrences that were discovered by *garimpeiros* using trial-and-error methods, this deposit was found by systematic geologic research and modern prospecting techniques. After Seahawk Minerals Ltd. acquired the land in May 1998, the company initiated an exploration program that included geologic mapping, trenching, and the geochemical analysis of 925 soil samples. Then, 45 core holes were drilled which outlined an emerald-bearing zone measuring 800 × 200 m. Preliminary mining activities started in September 2001.

The Piteiras property is situated directly between the Belmont and Capoeirana emerald mines. At all three deposits, the emeralds are found in a "blackwall zone" (phlogopite/biotite schist). Occasionally, they are concentrated in "shoots," where the crystals have the best color and can be quite large (the longest crystal found so far was 22 cm; an 18 × 9 cm crystal weighed 2.8 kg). The chemical composition and gemological characteristics of the Piteiras emeralds are very similar to those from the neighboring Belmont and Capoeirana mines. *RT*

Red beryl company goes belly up. G. Austin, *Colored Stone*, Vol. 15, No. 2, 2002, pp. 14–15.

Large-scale mining for red beryl in Utah's Wah Wah Mountains ceased in 2001 after a seemingly promising future. From 1992 to 1996, Kennecott Exploration Co. conducted detailed geologic mapping, core drilling, and

bulk sampling; ultimately, however, they concluded that the deposit was not economically viable. Subsequently, during 1997–98, Utah-based Gemstone Mining Inc. (GMI) conducted additional exploration (e.g., drilling and underground sampling) and evaluation of the faceted stones. Their results were favorable (especially the yield of cut stones per ton of ore), and GMI began large-scale open-pit mining in December 1998. The production was sold to Red Emerald Ltd. (REL), a related company (both were formed by Amelia Investments Ltd., headquartered in Gibraltar, U.K.) that was responsible for cutting and sales.

Despite activities by several marketing specialists to promote red beryl, REL experienced financial problems. Its management was blamed for bad decisions, such as turning down contracts with a television shopping network and a major jewelry supply company, which would have provided greater exposure for the rare gem. In June 2001, a board member decided not to make a \$2.5 million payment that was due to the claim owners, which led to the cessation of all mining and marketing activities by GMI and REL. Subsequently, equipment was sold off, and the property was reclaimed, as required by the state of Utah. The fate of approximately 6,000 carats of faceted red beryl remains uncertain, as does the future of the deposit. *MT*

Rubis trapiches de Mong Hsu, Myanmar [Trapiche Rubies from Mong Hsu, Myanmar]. V. Garnier, D. Ohnenstetter, G. Giuliani, and D. Schwarz, *Revue de Gemmologie*, No. 144, 2002, pp. 5–12 [in French with English abstract].

After a comparison of the geologic occurrences of trapiche emerald and trapiche ruby, and a discussion of the various theories proposed for their formation, this article presents the results of an investigation of the chemical compositions, and the solid and fluid inclusions, of six trapiche rubies from Mong Hsu. The study used advanced analytical techniques such as energy- and wavelength-dispersive spectrometry and "cold" cathodoluminescence.

The authors identify 12 minerals not previously reported as inclusions in trapiche rubies or as components of their skeletal "arms." The rubies show a chemical zonation that can be linked to variations in the chemical composition of the growth fluid. The chromium content, in particular, appears to be related to variations in the circulation of metasomatic fluids rich in REE (rare-earth element) fluorides. *RT*

Star garnets and star garnet cat's-eyes from Ambatondrazaka, Madagascar. K. Schmetzer, H. J. Bernhardt, and L. Kiefert, *Journal of Gemmology*, Vol. 28, No. 1, 2002, pp. 13–23.

Star garnets (some that also show chatoyancy) from Ambatondrazaka, Madagascar, are described with particular attention to the orientation of the ray-causing, acicular (needle-like) inclusions. The garnets are members of the almandite-spessartine series (70–73 mol.% and 18–21

mol.%, respectively), with appreciable (7–9 mol %) pyrope and minor (1–2 mol %) grossular and andradite.

Raman analysis indicates that the asterism is caused by oriented rutile needles, a common occurrence in garnets. The four- and six- rayed stars (which may appear in the same specimen) are seen when viewed perpendicular to the dodecahedral and octahedral faces, respectively. Oriented sillimanite lamellae were identified in the samples with chatoyancy. WMM

Star garnets from Ilakaka, Madagascar. K. Schmetzer and H.-J. Bernhardt, *Australian Gemmologist*, Vol. 21, No. 5, 2002, pp. 202–206.

Mineralogical and gemological properties are given for three cabochons of six- and/or four-rayed star garnets from the Ilakaka area of Madagascar. Compositionally they are almandine-pyrope; electron microprobe analysis of one sample yielded $\text{Alm}_{50.33}\text{Pyr}_{41.05}\text{Spe}_{1.26}\text{Gro}_{7.36}$, and measured R.I. and S.G. values were 1.773 and 3.96, respectively. The asterism is caused by a dense network of acicular inclusions oriented parallel to the two-fold or three-fold axes of the cubic garnet host. RAH

INSTRUMENTS AND TECHNIQUES

Gemchecker™ Professional valuation & appraisal module: G.A.A. Instrument Evaluation Committee Report. T. Linton and K. Frazer, *Australian Gemmologist*, Vol. 21, No. 5, 2002, pp. 215–218.

The Gemchecker™ Professional (Pro) is a computerized system for the management of gems and jewelry, from the identification of their components to the assignment of value, and also for stock control. Clients appreciate a clear, unambiguous presentation of information used in appraisals, even though they may have little appreciation of the complexities involved. The Gemchecker Pro provides a modular system to facilitate valuations, with components that are flexible, both in purchase and application; valuers only need to buy those modules appropriate to their particular business operation. Once the modules are in place, their function and operation is controlled by “pull-down” menus that allow rapid selection of functions. Examples are given for the valuation of loose diamonds, opals, and pearls. The system is most useful when several valuers are linked by a high-speed computer network. RAH

Observation des émeraudes traitées en luminescence U-VISIO® [Investigation of treated emeralds by the U-VISIO® luminescence method]. F. Notari, C. Grobon, and E. Fritsch, *Revue de Gemmologie*, No. 144, 2002, pp. 27–31 [in French with English abstract and figure captions].

Synthetic resins (typically epoxy) that have been used to treat emeralds have turned out to be less stable than originally believed (e.g., they change color, lose clarity). Therefore, such resins are sometimes removed and replaced by cedar-

wood oil. So that the emeralds can be accurately described on reports, it is desirable to determine the nature and quantity of resin residues they contain.

The presence of residues can be detected by microscopy, infrared spectroscopy, and Raman microspectrometry, but these techniques cannot accurately determine the nature and quantity of the resins. Such characteristics can be determined by U-VISIO®, an advanced luminescence analysis technique. The analytical procedures, as well as the performance of this method, are explained and illustrated with numerous photomicrographs. RT

JEWELRY HISTORY

Dogali, January 1887: An engraved sapphire by Giorgio Antonio Girardet for a Castellani brooch. L. P.-B. Stefanelli, *The Burlington Magazine*, Vol. 144, No. 1191, 2002, pp. 354–356.

In 1917, a brooch-pendant produced by the Roman goldsmith Castellani entered the collection of London's Victoria and Albert Museum. Manufactured in 1887 or 1888, the 9.4 × 5.2 cm brooch derives its form from a 17th century German prototype and contains a large heart-shaped sapphire engraved by Girardet to commemorate the tragic 1887 massacre of 500 Italian soldiers at Dogali in Ethiopia. The intaglio engraved on the sapphire's convex surface is richly populated with uniformed soldiers in battle, a mirror image of the central part of a print by Pogliaghi. CT

The Ottoman Treasury. E. Bilirgen and S. Murat, *Arts of Asia*, Vol. 31, No. 6, 2001, pp. 54–67.

The Fatih Kiosk at the Topkapi Palace in Istanbul houses the Ottoman Imperial Treasury and became a museum in 1924. Gold and jeweled objects, primarily from the 16th to 19th centuries, are stored and exhibited at the museum. The collection was expanded over the centuries as sultans added heirlooms on their ascensions, made purchases with both private and public funds, and accumulated the spoils of war. Gifts from foreign ambassadors and other rulers, as well as from artists and craftsmen, also augmented it. The museum now protects the priceless offerings left over time at the tomb of Muhammad in Medina.

Numerous items are of special interest to gemologists: the 86 ct pear-shaped, rose-cut Kasikci diamond; the Nadir Shah Throne studded with emeralds, rubies, and pearls; magnificent aigrettes, most of which are from the 18th century; jeweled figurines, trophies, and snuff and cigarette boxes; and 16th century gold and jade book bindings that are set with emeralds, diamonds, turquoise, and other gemstones. CT

Stories in precious stones. J. Zapata, *Art & Antiques*, Vol. 25, No. 5, 2002, pp. 70–75.

As prominent collectors (such as B. A. von Rothschild and J. P. Morgan) amassed important collections of Renaissance jewelry in the 19th century, jewelers of the time adapted

the original 16th century designs to satisfy public demand for similar pieces; this resulted in the Renaissance Revival style. The style is pictorial or even allegorical in nature, using pearls, colored gemstones, and enamel in artistic combinations rather than being dominated by large gemstones. The pleasing design motifs are easily understandable and today appeal to a sophisticated audience.

Collectors interested in jewelry from the 16th century can buy 19th century Renaissance Revival jewelry instead. Sought-after 19th century designers include Giuliano, Falize, and Vasters, while contemporary designers of Renaissance style jewelry include Buccellati and Lantuch.

CT

JEWELRY RETAILING

State of the jewelry industry. F. Costanza, *National Jeweler*, Vol. 96, No. 17, September, 1, 2002, pp. 50–52, 54, 56.

Retail jewelry sales in the U.S. have declined for two consecutive years, 2000 and 2001, after large gains in the 1990s. More significantly, jewelry sales as “share of wallet” declined 0.1% (in 2001 compared to 2000) as other big ticket items gained.

Total retail jewelry sales in the U.S. jumped from \$24.5 billion in 1989 to \$42.9 billion in 1999, before falling back to \$40.6 billion last year. Citing the Jewelers of America (JA) Cost of Doing Business survey, the article notes that loose diamonds (15.1% of total sales) and diamond jewelry (32.4% of total sales) continue their overwhelming dominance of retailers’ business. The next highest category was karat gold jewelry (11.1%), followed by colored stones (9.3%).

According to the JA survey, retailers’ gross margins have remained relatively steady over the past decade. Last year’s average was 49.3%, slightly higher than 2000 (47.4%). Margins were lowest at the high-ticket stores. Independent high-end jewelers reported an average margin of 45.6%, while mid-range independents and chain jewelers reported average margins of 50.2% and 50.7%, respectively. Designer and custom jewelers reported the highest average margin at 59%.

The survey, citing a report from Ken Gassman of Davenport Associates, forecasts strong U.S. jewelry sales increases in the near future: \$42.3 billion this year, rising to \$51.5 billion in 2005.

RS

SYNTHETICS AND SIMULANTS

Growth of piezoelectric quartz crystals of large dimension on seeds parallel to the (10 $\bar{1}$ 1) face and lengthened along the Y-axis. I. B. Evseeva, V. E. Khadji, and P. P. Chvanski, *High Pressure Research*, Vol. 20, 2001, pp. 211–218.

Colorless synthetic quartz crystals have been grown in large quantities for decades, primarily for their piezoelectric properties, using well-developed hydrothermal tech-

nologies. The seed plates used to grow the crystals are usually cut parallel to the basal face {0001} and elongated in the direction of either the hexagonal prism [10 $\bar{1}$ 0] or the trigonal prism [11 $\bar{2}$ 0].

Details are given of a new growth technique that produces large piezoelectric quartz crystals using seed plates cut parallel to the negative rhombohedron face {10 $\bar{1}$ 1} and elongated along either the X- or Y-axis. The method requires hydrothermal solutions of sodium hydroxide (4%) and sodium carbonate (7%) with the admixture of lithium nitride. The temperature of crystallization is 330°–410°C, with pressures up to 150 MPa; growth rates range from 0.45 to 0.65 mm/day. These crystals are described as rx- or ry'-crystals in Russia, and have been grown in sizes up to 410 mm and 120 mm along Y- and X-axes, respectively. This technology could be applied to the synthesis of amethyst crystals. TL

The growth of sapphire single crystals. A. Golubovic, S. Nikolic, S. Djuric, and A. Valcic, *Journal of the Serbian Chemical Society*, 2001, Vol. 66, No. 6, pp. 411–418.

The optimum conditions for growing electronic-grade crystals of colorless sapphire by the Czochralski (pulling) technique in iridium crucibles, in both an air and argon atmosphere, were determined theoretically and confirmed experimentally. The hydrodynamic condition of the melt is critical and is controlled by convection of three types: forced convection caused by the rotation of the crystal and/or the crucible, buoyancy-driven free convection, and thermocapillary surface convection. These variables were considered in the theoretical calculations.

The best-quality synthetic sapphire crystals were obtained when the crystal rotation speed was 20 rpm, the pulling rate was 3.5 mm/hour, and the cooling rate after crystal growth was about 50 K/hour. The argon atmosphere was not suitable because it resulted in the formation of light-scattering particles (a variant of Al₂O₃) within the crystals. Growth in an air atmosphere yielded good crystals when the temperature was less than 1,300 K. Above this temperature, oxidation of iridium from the crucible resulted in the formation of iridium oxide (IrO₂), which converted to metallic iridium that became incorporated into the growing crystal. TL

Historical review of quartz crystal growth. F. Iwasaki and H. Iwasaki, *Journal of Crystal Growth*, Vol. 237–239, Part 1, 2002, pp. 820–827.

The history of the synthesis of quartz crystals is reviewed, and three stages are recognized:

1. The basic work was performed in the late 19th and early 20th centuries by European mineralogists and chemists who investigated growth conditions of quartz. The first major results were obtained in 1909 by Dr. G. Spezia (Turin University, Italy), who grew synthetic quartz on seed crystals in hydrothermal solutions. However, the crystals were small and the growth rate was slow.

2. During World War II, larger quartz crystals were synthesized and used for industrial and military purposes (e.g., oscillators) in Germany and England. In both countries they were grown hydrothermally by the isothermal method based on the difference in the solubilities between fused quartz as a nutrient and crystalline quartz as a seed.
3. The modern quartz growth industry developed in 1949, when it was recognized in England that quartz crystals could be grown hydrothermally by the temperature gradient method (a variation of Spezia's technique) using crushed quartz as a nutrient. Since then, synthetic quartz has been mass-produced by various hydrothermal methods in the U.S., Russia, and Japan; the seed type chosen is especially important in commercial production processes. Various color varieties of synthetic quartz seen in the gem trade today are grown primarily in Russia using specialized hydrothermal techniques developed in the last decade. TL

Inclusions related to catalyst and medium for transmitting pressure in diamond single crystals grown at high temperature and high pressure from the Fe-C system. L. Yin, M. Li, Z. Hao, and J. Zhang, *Journal of Physics D: Applied Physics*, Vol. 34, No. 12, 2001, pp. L57–L60.

Single-crystal synthetic diamonds are most often grown from solution in a metal catalyst–carbon system at high pressure and high temperature (HPHT). Graphite is used as a carbon source, the transformation of graphite to diamond is accomplished with a molten catalyst (Fe or Ni or Co), and pyrophyllite (a hydrated aluminum silicate mineral) is used as a medium for transmitting pressure. This process gives rise to the formation of inclusions in the synthetic diamonds in a number of ways: (1) by the reaction of liquid iron with diamond or graphite, (2) by the reaction of liquid iron with the element components of pyrophyllite, or (3) by the reaction of the diamond or graphite with silicon from pyrophyllite.

The inclusions in small (~0.6 mm) crystals of synthetic diamond were studied by transmission electron microscopy, energy-dispersive X-ray spectrometry, and electron diffraction techniques. Four types of inclusions were identified: Fe₃C (orthorhombic), FeSi₂ (orthorhombic), SiO₂ (hexagonal), and SiC (cubic). Knowledge of these inclusions is important since their nature and abundance can affect hardness, thermal conductivity, optical absorption, and other properties of the synthetic diamonds. KSM

Ladder-shaped hydrothermal growth of color [sic] corundum crystals. Z. Chen, J. Zheng, C. Zhang, H. Huo, W. Zhou, and H. Shen, *Journal of Synthetic Crystals*, Vol. 31, No. 1, 2002, pp. 18–21 [in Chinese with English abstract].

Researchers in Guilin, China, have developed a new type of autoclave for the hydrothermal growth of synthetic corun-

dum. This autoclave has a growth ladder (made of gold wires) capable of accommodating six to 10 seed crystals simultaneously. The crystal growth zone of the autoclave is 300 mm long and has a temperature gradient of 0.27°C/cm. The temperature in the growth zone is 505°–515°C, and in the dissolution zone is 550°–580°C. The pressure is about 1,500–2,000 atmospheres.

Various colors of synthetic corundum (red, pink, yellow to orange-yellow, yellowish green, brownish red, and “white”) have been grown successfully by the addition of different dopants (e.g., Cr³⁺, V³⁺, Mn³⁺, Co³⁺, Ni²⁺, Ni³⁺). The concentrations of these impurities in the growth environment are controlled by the diameters of openings in the capsules containing them. Good-quality synthetic corundum crystals of 30 × 25 × 10 mm (60–90 ct) are obtained in seven to 10 days. TL

Moissanite: Genesis, synthesis, and identification. E. Melnikov et al., *Gemological Bulletin* (Gemological Society of Russia), No. 1 (4), 2002, pp. 9–15.

This article reviews the history, multiple uses, synthesis, and identification of synthetic moissanite (SiC), from its accidental synthesis in 1893 through its current use as a gem material. It also reviews the worldwide occurrences of natural moissanite (which is rare and not of gem quality) and its various crystallographic types.

The gemological properties of synthetic moissanite are emphasized, with particular attention to the traditional methods that can be used to separate it from diamond; these include specific gravity (3.32; diamond is 3.52), inclusions, and recognition of optic character. The most common inclusions, which are characteristic of both colored and colorless synthetic moissanite produced in Russia and the U.S., are growth channels. Small black graphite inclusions and combinations of inclusions (mineral + channel or negative crystal + channel) are sometimes observed as well. The easiest to observe and most reliable feature for distinguishing synthetic moissanite from diamond is the doubling of the facet junctions due to the anisotropic optic nature of the 6H polytype that is currently used in jewelry. Advanced (spectroscopic) techniques for identification also are discussed. Synthetic moissanite has strong absorption bands with maxima near 420–430, 480, and 840–870 nm. VD

TREATMENTS

Beobachtungen an hitzebehandeltem Rubin mit künstlicher Rissheilung [Observations on heat-treated ruby with artificially healed fissures]. H. A. Hänni, *Gemmologie: Zeitschrift der Deutschen Gemmologischen Gesellschaft*, Vol. 50, No. 3, 2001, pp. 123–136 [in German with English abstract].

This article provides a comprehensive review of the characteristic features of the fracture fillings and healed fractures in rubies that result when fluxes are used in conjunc-

tion with heat treatment. Heat treatments designed to heal fissures in rubies involve the use of a variety of synthetic or natural fluxes (e.g., lithium tetraborate or borax). During heat treatment, the flux forms a melt that spreads over the surface of the stone and is drawn into fissures and cavities. On cooling, the flux crystallizes and the fissures are healed. The flux may remain amorphous and glassy, but very often devitrification products are formed.

The results of this flux-assisted heat treatment are not only healed fissures with the appearance of natural "fingerprints," but also residual portions of the flux material ("glass") that occur as fine droplets, channels, or thin films in the fissures. Depending on the amounts of such "glassy" residues in a ruby, the degree of enhancement can be categorized as minor, moderate, or significant/prominent.

Claudia S. D'Andrea

Changing diamond colour. V. G. Vins, *Gemological Bulletin* (Gemological Society of Russia), No. 3, 2001, pp. 19–30.

This paper discusses the changes that can be made in the color of gem diamonds by both high-pressure, high-temperature (HPHT) treatment, and by β HPT treatment (a combination of irradiation with 3 MeV electrons, followed by annealing at about 1,230°C). It examines the hypothesis that HPHT treatment removes brown color from type IIa diamonds by reducing plastic deformation in the crystal, and the alternative proposed by Smith et al. (Fall 2000 *Gems & Gemology*, pp. 192–215) that some other color-causing defect(s) located along the deformation planes is(are) destroyed by the treatment.

The results of several experiments, not previously published in English, are presented. In the 1970s, Russian researchers created a brown color in originally colorless diamonds by plastically deforming them in the laboratory. In other experiments, annealing of brown diamonds at about 1,530°C—which is sufficient to break down the N-related color-causing defects in diamond (such as the H3, H4, and N–V centers)—did not change their color. Further evidence directly indicates that HPHT treatment reduces deformation: The intrinsic Raman peak for diamond (at 1332 cm^{-1}) narrows considerably after treatment, and the diamond becomes less resistant to mechanical abrasion (due to a reduction in the dislocation density in the crystal).

Visible and infrared spectra are presented for different types of diamond following HPHT treatment, and they are interpreted with respect to the changes among the various N-bearing defects (both color-causing and IR-absorbing). An IR band at 3107 cm^{-1} , associated with hydrogen, was created or increased in most of the type Ia samples as a result of the HPHT treatment. Further experiments on gray type Ia diamonds (relatively rich in hydrogen) showed large increases in this peak and other hydrogen-related absorptions, and other changes leading to a "straw yellow" color.

β HPT treatment was applied to both type Ia and type IIa diamonds. Originally near-colorless type IIa diamonds were

blue after irradiation, but turned a faint grayish brown, rather than colorless, after the annealing. Type Ia diamonds were greenish blue after irradiation, and either yellow-green (about 80%) or red after the annealing. The author reported a strong, broad band at 470 nm in the yellow-green diamonds that appeared after the irradiation and grew appreciably on annealing, as well as spectral features previously presented in the literature. Diamonds that turned red from this treatment contained nitrogen in A aggregates, but not in platelets. In all of these type Ia samples, the treatment substantially reduced brown components of the color.

Ilene Reinitz

Color changing in synthetic diamonds: Influence of growth conditions. V. Vins, *Gemological Bulletin* (Gemological Society of Russia), No. 1 (4), 2002, pp. 28–36 [in Russian with English abstract]

This article complements the study of natural diamonds [see previous abstract] subjected to HPHT and β HPT treatments with similar experiments on cut synthetic diamonds (type Ib) grown in the ranges of 1,350°–1,390°C to 1,650°–1,740°C. The same experimental and interpretative procedures, the latter based primarily on optical spectroscopy, were used. Transformations of optically active crystal lattice centers were confirmed and explained on the basis of the nature and chemical composition of the principal impurities (mainly nitrogen), structural defects, and the variable growth rates and temperature ranges.

VD

Color modification in HPHT-annealed diamonds. C. P. Smith, *Rapaport Diamond Report*, Vol. 25, No. 17, May 3, 2002, pp. 48–50.

In April 1999, Lazare Kaplan International and General Electric introduced a new color-modification process that successfully alters the color of certain diamonds. It was eventually determined that the process initially involved the application of high pressure, high temperature (HPHT) technology to remove the brown color in type IIa diamonds, leaving them colorless to near-colorless. Subsequently, HPHT treatment of some type IIa stones produced a pink color, and some type IIb diamonds have become blue. Type Ia diamonds can show orange, yellow, and yellow-green colors following HPHT treatment; occasionally dark brown-purple and gray are produced. Color changes resulting from the HPHT treatment are due to a reconfiguration of the atomic arrangement of the lattice.

It is expected that increasing numbers of HPHT-treated diamonds (both natural and synthetic) will become available in a variety of colors, as they are currently being produced in at least five countries (U.S., Russia, Ireland, Israel, and China). The features that can be used to identify HPHT treatment are very dependent on the type and color of the diamond being analyzed; important or questionable diamonds should be sent to a laboratory with the appropriate equipment and experience.

MT

High-temperature annealing of colour centres in diamond.

A. T. Collins, in Y. Tzeng et al., Eds., *Proceedings of the Sixth Applied Diamond Conference/Second Frontier Carbon Technology Joint Conference (ADC/FCT)*, Auburn, Alabama, August 6–10, 2001, pp. 223–231.

This paper presents spectral data for irradiated and annealed diamonds, and discusses the changes to their colors and nitrogen-bearing defects produced by various annealing conditions. Synthetic type Ib and natural type Ia diamonds (with both A and B aggregates) were irradiated at 2 MeV with either electrons or neutrons to create an abundance of vacancies. Then, some samples were heated repeatedly at successively higher temperatures, from 1,000°C to 1,600°C in an inert atmosphere, while others were subjected to HPHT treatment (about 2,300°C and 5–6 GPa). Spectra were obtained from the mid-infrared to the visible range, and presented in pairs (before and after treatment) to illustrate features relating to changes in N aggregation and in the concentration of various color-causing centers.

Annealing of type Ia diamonds without high pressure caused significant development of H2 centers, and reduced continuum absorption in the same spectral region as the peaks of the H3 center, changing the color from “orange/yellow” to “yellow/green.” The same treatment applied to synthetic type Ib diamonds produced weaker peaks for the H2 and H3 centers, and a strong peak at 1.945 eV (637 nm) that colors the diamond pink; the infrared spectra for these samples showed increasing aggregation of N (that is, some development of A aggregates) as well. HPHT treatment also affects the aggregation state of N, causing aggregates to break apart and release single N atoms.

This spectral information, along with the author’s previous work, illustrates the successive creation and destruction of a series of N-bearing defects with increasing annealing temperature. The final products (both in terms of the defects and the colors they produce) depend on the temperature and duration of annealing, as well as on the initial N-aggregation state of the diamond. Attempts to fit spectral data to rate equations for the formation and breakdown of these centers support the idea that HPHT treatment is a non-equilibrium process. In particular, aggregates of N break apart rapidly during such treatment (i.e., more quickly than they can form new defects with migrating vacancies). Thus, at the highest temperatures of HPHT treatment, all previous N-bearing defects and color centers are broken down, and the remaining cause of color is single-substitutional N from the disaggregation process. *Ilene Reinitz*

Hochdruck-Hochtemperatur-Behandlung natürlicher Diamanten [High temperature-high pressure treatment of natural diamonds]. K. Schmetzer, *Goldschmiede Zeitung*, Vol. 100, No. 1, January 2002, p. 92 [in German].

On October 4, 2001, De Beers Industrial Diamonds (Pty) filed three patent applications on transforming the color of

brown or gray type II diamonds by high pressure, high temperature (HPHT) annealing. The following transformations are described: brown type IIa stones to pink (according to WO 01/72404A1), gray type IIb stones to blue (according to WO 01/72405A1), and brown type IIa stones to colorless (according to WO 01/72406A1). The various temperature and pressure conditions, time required for the conversions, and other experimental details are also presented.

De Beers stated that it intends for these to be “protective patents,” and it will not produce HPHT-treated diamonds for commercial purposes. The author notes that in the international search report for all three De Beers applications, four previously published HPHT literature references and three previously published patent documents were cited [see *Gems & Gemology*, Fall 2001, pp. 257–258, for one such patent application by General Electric] that seem to preclude the success of these applications. Thus, it remains to be seen if De Beers will be able to fulfill its “protective patent” objective. *AAL*

LRM spectrum characteristic of filled glass in heat-treatment [sic] rubies. B. Xi, R. Xu, H. Gao, and X. Guan, *Journal of Gems and Gemmology*, Vol. 3, No. 4, 2001, pp. 5–7 [in Chinese with English abstract].

Natural rubies are usually enhanced by heat treatment in a flux, and secondary glasses may be formed that then remain in the gems. These fluxes are commonly similar in appearance to glass inclusions found in flux-grown synthetic rubies. To differentiate between these two types of glasses, the chemical compositions and structural characteristics of both types were determined using electron microprobe and laser Raman microspectrometry (LRM) techniques.

Four types of glasses were found in the heat-treated natural rubies: sodic aluminosilicate glass, Na-P-Al glass, B-Na-Al glass, and aluminosilicate glass. Chemically, these glasses are significantly different from flux inclusions found in synthetic rubies. They differ not only in major elements, but also in trace elements. For example, Pb, W, Mo, and Bi present in synthetic rubies were not detectable in the glasses. The Raman spectra of the two materials also are distinct. *TL*

Research on radiation-induced color change of white topaz. Y. Wang and Y. Gu, *Radiation Physics and Chemistry*, Vol. 63, Nos. 3–6, 2002, pp. 223–225.

A new method of turning white topaz blue is described that uses a 3–5 MeV scanning electron beam from a linear accelerator, in conjunction with a cooling device to minimize cracking of the topaz. Following irradiation, samples are heated to 180°–280°C to stabilize the blue color. Although the color is stable in sunlight, it can be removed by heating to temperatures >450°C.

Electron-beam irradiation has a shorter processing time than fast-neutron radiation (since there is no residual radioactivity). One major drawback is that this technique is not suitable for larger (over 14 × 16 mm) samples. *AI*

MISCELLANEOUS

Crimestoppers. C. Langford, *Canadian Diamonds*, Spring 2002, pp. 36–38, 40.

The Royal Canadian Mounted Police (RCMP) formed a three-member Diamond Protection Service (DPS) in 2001 in response to criminal potential associated with Canada's emerging diamond industry. The team determined that criminal interests, though not yet established or organized, were keenly aware of Canada's diamond potential, and the DPS decided their best defense was a good offense. Consulting with police forces and industry professionals worldwide, they learned about the nature of diamond crime in order to recognize emergent patterns at home. The DPS believes that partnership with all phases of the industry and various Canadian and international intelligence services will enable their success. They have educated other divisions of the RCMP about diamond crime and have created proactive policing policies aimed at prevention. *CT*

The discreet tycoon. R. Weldon, *Professional Jeweler*, Vol. 5, No. 1, 2002, pp. 20–22, 26; **Lev Leviev's Angolan connection.** R. Weldon, *Professional Jeweler*, Vol. 5, No. 2, 2002, pp. 19–21.

This two-part article provides details of a long interview with Lev Leviev, chairman of the Israel-based diamond company LLD (reportedly the world's top-ranking diamond manufacturer by value). The first part describes how Leviev, a quiet, self-effacing man, achieved sales of \$2 billion in 2000, divided equally between rough and polished, by developing his own diamond sources, as well as opening polishing operations in several Russian cities. The extent of his operations makes him a serious competitor to De Beers.

Leviev entered the diamond business at 16 and became one of De Beers's youngest sightholders a decade later. By 1986, his exports exceeded \$23 million. By 1994, they were 10 times that amount. A big turning point came in 1992 when, with a rabbi's blessing, he began doing business in Russia. That was just after the fall of the Soviet Union when opportunities—and risks—abounded. He eventually relinquished his De Beers sight and diversified into a number of businesses, including real estate.

The second part of Weldon's report deals with Leviev's Angolan operations. In October 1999, De Beers stopped buying diamonds from Angola out of concern that some may have come from UNITA, the rebel group engaged in a long civil war with the government. Early in 2000, the Angolan government reorganized its diamond mining and marketing agencies into a single company called the Angola Selling

Corp. (Ascorp). The government owns half of Ascorp; Leviev and an Antwerp company, Omega Diamonds, own the other half.

As a result of this move, Leviev was named sole sales agent for Angola's diamonds. While he wouldn't reveal how he obtained that marketing deal, he did say that the government has profited greatly from it, as tax revenues rose from \$10 million to \$60 million in two years. Leviev is certain that no diamond sold by Ascorp comes from conflict origins, but he does acknowledge that stones are still smuggled out of the country illegally. Leviev is also diversifying into other countries, buying an offshore operation in Namibia and prospecting in Botswana. He is also looking at various diamond projects in Canada. *RS*

India in-depth. C. Even-Zohar, *Mazal U'Bracha Diamonds*, Vol. 16, No. 139, November 2001, pp. 49–68 passim.

The modern diamond-cutting industry in India began in the mid-1960s, with inexperienced cutters using primitive equipment and polishing a small amount (~5%) of the world's production, much of which was of poor quality [see Spring 1998 *Gems & Gemology*, pp. 4–23, for a history of the Indian cutting industry from 1966–96]. Since then, India's contribution to diamond manufacturing has risen enormously, and it now cuts and polishes the largest share of the world's diamonds: 55% by value, 80% by weight, and 90% by the number of stones polished (~850 million; average size is 2.3 points). This is achieved by ~750,000 highly trained cutters who are well paid (by local standards; currently \$120–\$150/month). Well-cut diamonds are produced with modern equipment, and are sold worldwide by ~7,000 diamond exporters. This "made in India" success story has been achieved, in part, because of an enlightened government strategy that is supportive of export-led growth.

This article contains a wealth of information on the current state of the Indian diamond industry. The topics range from an analysis of the geographic sources of the imported supply of rough (essentially all is imported), through government policies (e.g., the requirements for obtaining import licenses), to the role of some 50 banks that finance the industry (the current domestic indebtedness of the industry is ~\$1.7 billion). Of particular interest to gemologists are data on productivity (e.g., workers average four 2.5 point, or ten 1.0 point stones/day), and the average production costs for each polished stone (e.g., \$0.50 for a 1.5–3.0 point stone, and \$1.00 for a 15 point stone). Local sales of polished diamonds have grown considerably in recent years, making the domestic Indian diamond market one of the fastest growing in the world. *AAL*

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