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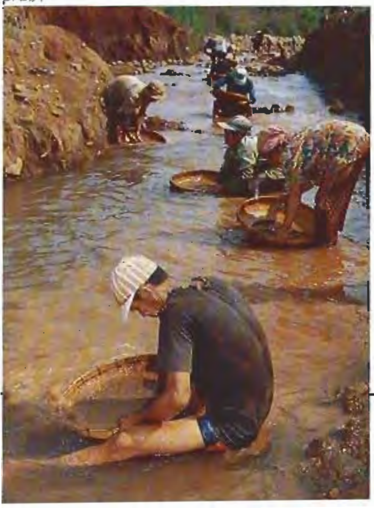

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ABOUT THE COVER: The modern history of the diamond industry started in the late 1860s, with the discovery of a bright pebble on a farm in South Africa. Soon, prospectors had spread throughout the Kimberley area (and, eventually, into neighboring countries) looking for—and finding—many major alluvial deposits and the host pipes themselves. For more than a hundred years, countries on the African continent dominated the supply of gem diamonds. Even today, they continue to provide millions of carats annually for the consumer market. The lead article in this issue, Part I of a two-part series, provides a fascinating, and factual, history of the diamond discoveries in southern Africa. The 27.74 ct yellow diamond in the pendant to this diamond necklace is of African origin; it is surrounded by 19 circular-cut diamonds, which range from 0.90 to 2.53 ct. Necklace by Harry Winston; photo courtesy of Christie's.

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Gems & Gemology welcomes the submission of articles on all aspects of the field. Please see the Suggestions for Authors in the Spring 1995 issue of the journal, or contact the editor for a copy. Letters on articles published in *Gems & Gemology* and other relevant matters are also welcome.

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DIAMOND PROSPECTING AND MARKET PROSPECTS

Richard T. Liddicoat, Editor-in-Chief

The search for diamonds has been a preoccupation of wealth-seekers for countless years. The early discoveries in India, Brazil, and South Africa clearly were fortuitous. More recent discoveries in Africa, as well as on other continents, also have had an element of luck, although many have been based on sound scientific principles. These principles have developed (slowly at first) since the 1870s, when the significance of the kimberlite pipes in South Africa was first recognized. In the late 1930s, on the basis of these same principles, Professor Vladimir Sobolev discerned the geologic similarities between the diamond-producing areas of South Africa and those of the Yakutia region—leading to the discovery and development of the prolific Siberian diamond mines since the 1950s.

In the two-part article by Dr. Bram Janse, an internationally recognized expert in diamond exploration, the history of diamond discoveries on the entire African continent is discussed. As the "plot" unfolds, one is able to follow the evolution of the discovery and production of diamonds from an increasing number of African countries, as well as the fundamental geologic concepts that now form the basis of all modern exploration programs, but throughout the world.

The success of diamond exploration has been phenomenal, and some have expressed concern over the prospect of a gem diamond glut as production from new sources has become available. The influx of diamonds from Russia (since 1959), Botswana (since the early 1980s), and Australia (since the mid-1980s) has increased the supply at a dramatic pace—since the mid-1980s alone, from less than 50 million to more than 100 million carats annually. Notwithstanding the continual increase in the supply of diamonds over more than a century, there has been no obvious effect on prices, nor on the appeal of diamonds to the buying public (except, possibly, to make them even more appealing!). Demand for diamonds and diamond jewelry, fueled first and foremost by the American market, subsequently by the Japanese market (where present demand has been stifled by a pervasive recession), and, most recently, by other Pacific Rim countries, continues unabated. Thus, the market would be expected to absorb moderate increases in production from new discoveries without any significant distortion.

Among diamantaires, there seems to be more concern (warranted or not) about the potential impact of jewelry-quality synthetic diamonds, should they ever become available at a fraction of the price of natural stones. The second article in this issue, and the chart that accompanies it, represent how we at GIA feel that this challenge can best be tackled: through research and education. The well-informed jeweler-gemologist can be just as effective in controlling the impact of synthetic diamonds as the market has been in managing the influx of natural ones. ❑

A HISTORY OF DIAMOND SOURCES IN AFRICA: PART I

By A. J. A. (Bram) Janse

For more than 100 years, Africa has produced large commercial quantities of diamonds and important individual stones. The earliest official finds were made from approximately 1867 onward, in sands and gravels of the Orange and Vaal Rivers in South Africa. Subsequently, diamonds were found in "hard rock" kimberlites and, most recently, in off-shore deposits along the western coast of South Africa and Namibia. Important discoveries have been made in many other African countries. Angola, Botswana, Central African Republic, Ghana, Namibia, and Zaire have now joined South Africa as being among the top 10 diamond-producing countries worldwide. Part I of this two-part series examines the fascinating history of these numerous discoveries in southern and central Africa from the 19th century to the present. Part II will look at eastern and western Africa, as well as the history of diamond prospecting, mining, and production on the African continent.

Although diamonds have been known for more than 2,000 years, with the earliest discoveries in India, large-scale mining and distribution date only from the late 1860s and the first finds in Africa. For almost a century, Africa—and especially South Africa—dominated diamond production, representing more than 98% of world output from 1889 to 1959. Many of the most famous stones ever to enter the gem market originated from these African deposits. In addition, much of our current knowledge about diamond occurrences, exploration, and mining comes from the African diamond fields. And the history of these discoveries is among the richest in the archives of gemology.

The first reliable records of diamond finds in Africa date from the late 1860s ("Diamonds are trumps," April 18, 1867). These followed the earlier finds in India several centuries B.C. (recorded in Arthasastra and Ratnapariska Sanskrit texts, as reported in Legrand, 1984); Borneo in the 10th century A.D. (Legrand, 1984); Brazil in the 1720s (Sarmento, 1735; Bruton, 1978*); Russia in the 1830s (Rose, 1837, pp. 352-374; Webster, 1975); the United States in the 1840s (Shepard, 1846; Kunz, 1892; Sinkankas, 1976); and Australia in the 1850s (Hargraves, 1851; Atkinson et al., 1990). In most of these earlier instances, the diamonds were mere mineralogical curiosities, found as occasional by-products in the recovery of gold from sands and gravels in stream beds. Through the ages, production from India and Borneo reached Europe only as a trickle of large (over one carat) stones that were used mainly as adornments for sovereigns and their consorts, with smaller stones used for engraving and cutting tools. The Brazilian deposits provided a steady supply of small stones after 1730 (Lenzen, 1970), but large quantities of stones of significant size (including many 15 ct and above) came only with the exploitation of the South African diamond fields from 1870 onwards (figure 1). In general, this sudden increase in supply coincided with the new wealth generated by the Industrial

ABOUT THE AUTHOR

Dr. Janse, president of Archon Exploration Pty Ltd. (Perth, Australia) and director of KWG Resources (Montreal, Canada), has 37 years of experience in diamond exploration.

Please see Acknowledgments at end of article.

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Figure 1. Africa was the dominant source in the world diamond market for almost a hundred years after the first pieces of rough were reported in South Africa in the 1860s. This suite of jewelry, designed by Gianmaria Buccellati, was fashioned from predominantly African rough collected over many years. The diamonds weigh a total of 344.11 carats. Courtesy of Buccellati of Beverly Hills, California; photo ©Harold & Erica Van Pelt.

Revolution and the attendant increased demand for luxury goods by a broader range of consumers.

This article reviews the history of the major discoveries of alluvial diamonds and kimberlite pipes throughout the African continent, from the earliest—in February 1867—near Kimberley, in South Africa, to the most recent discovery—in 1990—in the Sahara Desert, in Algeria (figure 2). The stories of the early diamond discoveries have been told many times, but many have become distorted and bowdlerized in the retelling. As much as possible, the information provided here has been culled from original sources (archival issues of periodicals and photocopies or excerpts of original documents) or recollections of people directly involved in the events described. Please keep in mind that the quality of reporting in 19th-century periodicals is often not as high as in recent ones, in that there was less opportunity for on-the-spot investigation. As a result, much of the evidence was based on hearsay. Likewise, personal recollections often contain incorrect information caused by wishful thinking and faulty memory. There are several other interesting stories that could have been told, but they were omitted because they could not be substantiated.

The following is a country-by-country account (basically, from south to north and from east to west) of the progression of major diamond discoveries and exploitation in Africa. Part I surveys the important diamond-producing countries in southern and central Africa. Part II, to be published in an upcoming issue

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**Wherever two references are quoted with widely different years, the first reference indicates the earliest record that I have found, whereas the second reference is the more accessible and comprehensive. Note that they sometimes differ in detail and interpretation.*

Figure 2. This map of Africa shows the countries in which diamonds and/or kimberlite or lamproite pipes have been found, highlighting those that are major diamond producers.

of *Gems & Gemology*, will cover eastern and western Africa, and will provide a historical perspective on the techniques of prospecting and discovery, the development of mining methods, the recovery of diamonds, and the people involved in these activities. Part II will also discuss those countries in which only sporadic occurrences of diamonds and/or pipes have been found, or for which only unsubstantiated accounts have been published (Burkina Faso, Cameroon, Congo, Gabon, Kenya, Malawi, Mozambique, Nigeria, Uganda, and Zambia).

SOUTH AFRICA

South Africa is the most significant diamond-producing country on the African continent. The modern diamond industry was born here, and within five years after the initial discovery of alluvial diamonds, large quantities were being recovered from "hard rock" kimberlite sources. In fact, South Africa is considered the type locality for the occurrence of diamonds in igneous host rocks, such as kimberlite pipes, which were first discovered there in 1869 and recognized as such in 1872. The methods and special equipment now used worldwide for the recovery of diamonds were developed here.

Diamond production from kimberlite pipes around Kimberley exceeded one million carats within the first year of exploitation by local miners ("diggers"). The largest diamond ever found, the Cullinan (3,106 metric carats), and many other very large diamonds were found in South Africa. This country has been a steady producer of several millions of carats annually up to the present, and important new discoveries are still being made.

The First Alluvial Diggings. Although a few diamonds were allegedly found earlier (Balfour, 1992; Liddicoat, 1993), the first officially recorded diamond on the African continent was found in the southern hemisphere's summer of 1866/1867, either as early as December 1866 or as late as February 1867 (Robertson, 1974*). This stone, which weighed 21.25 old carats,** was subsequently cut into a 10.73 ct brilliant and named the Eureka (figure 3).

This stone was found on a farm named De Kalk, in lime-cemented gravels of a terrace along the southern banks of the Orange River, which at that time formed the boundary between the Cape Colony and the Orange Free State (figure 4). However, there are several different versions of its discovery.

The earliest public reports appeared in the *Colesberg Advertiser* ("The wonderful South African diamond," April 9, 1867) and two Cape Town newspapers, the English *Cape Argus* ("Diamonds are trumps," April 18, 1867) and the Dutch *Het Volksblad* ("Gerucht over een diamant . . . ," April 18, 1867), which picked up the report from the *Colesberg Advertiser*. *Het Volksblad* ("Een Kaapsche diamant," April 30, 1867) carried the story that an experienced diamond cutter from Holland, Louis Hond, on request of Colonial Secretary Richard Southey, had identified a pebble "found by a Mr. O'Reilly somewhere along the Orange River" as a genuine diamond of 21.3 ct. (It remains unexplained why an experienced diamond cutter, such as Louis Hond, would have moved from Holland to Cape Town *before* it became known that diamonds were actually found in South Africa. Perhaps the knowledge of earlier diamond finds [see Balfour, 1992] was more widespread than has been reported, but this cannot be substantiated.) The actual location of the discovery was first mentioned in the *Colesberg Advertiser* ("Diamond mining," July 16, 1867) as a farm named "De Kalk." That article stated that Mr. Hond and his partner (a Belgian named Mons) were prospecting there and had found more diamonds.

Figure 3. The 10.73 ct yellow diamond known as the Eureka was reportedly faceted from the earliest recorded diamond in Africa, found in late 1866 or early 1867 on De Kalk farm near the Orange River. Photo courtesy of De Beers.

The *Colesberg Advertiser* ("Nelly Jacobs . . . ," July 30, 1867) and the London *Journal of the Society of Arts* ("Precious stone . . .," October 4, 1867)—as well as a memorandum dated June 23, 1868, from Hopetown magistrate William B. Chalmers (cited in Weakley, 1869, and Robertson, 1974)—refer to the finder as a little girl, daughter of a poor Boer farmer named Daniel Jacobs, who lived on De Kalk farm. The *Colesberg Advertiser* even invented a name for the girl, "Little Nelly," but from Robertson (1974) we now know that she was called Fredrika (shortened to Riekie—pronounced "reekee" in Dutch/Afrikaans). The *Cape Argus* ("Twenty diamonds found . . . ," October 31, 1868) published a map showing the location of the De Kalk farm, situated in Hopetown district along the left bank of the Orange River, about 30 km (18 miles) upstream from where it joined with the Vaal River.

The Chalmers memorandum describes the diamond as a pretty, white stone, a plaything of the little girl, which attracted the attention of a neighbor,

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**A photograph of the first diamond in Robertson's book (opposite p. 64) shows a label with the date 7th February, 1867, written by Chalmers. I think that this may be the date of Van Niekerk's visit to the Jacobs homestead.*

***The old carat was slightly larger than the metric carat, which was officially adopted by De Beers in 1920 (De Beers Annual Report for 1988) and by South Africa in 1923 (Williams, 1932).*

Figure 4. The first diamonds reported—and, subsequently, most of the major mines—in South Africa were located in the area between the Orange and Vaal Rivers. Note that the Kimberley-area mines are shown here in relative position, not precise to scale, because they were clustered in such a small area.

Schalk Van Niekerk, when he was visiting in February 1867.* He offered to buy it, but Mrs. Jacobs scoffed at the idea of selling a mere pebble and gave it to him (Chalmers' account does not say what the little girl thought of this). Chalmers states that "Van Niekerk was a very shrewd man with an enquiring turn of mind" and credits him with "bringing to light the existence of diamonds along the Orange River." Van Niekerk gave the pebble to a local trader/hunter, John O'Reilly, to take it to Hopetown to see if it was worth anything, as he thought that it was a diamond. O'Reilly showed it to several people in Hopetown, including Chalmers, who all laughed at the idea that the pebble might be a diamond. Nevertheless, Chalmers says he advised O'Reilly to send it to Dr. Atherstone, a physician and self-taught geologist/mineralogist living in Grahamstown.

Subsequently, Chalmers wrote that O'Reilly then went on to Colesberg where the town clerk, Lorenzo Boyes, sent the stone to Dr. Atherstone by letter, dated March 12, 1867 (see Chalmers' letter of January 20, 1969, cited in Robertson, 1974). Atherstone immediately responded that it was a diamond of 21.25 ct, worth £500, and that he would like to send it to Colonial Secretary Southey in Cape Town (Atherstone, 1869).** On April 16 or 17, Southey showed the stone to Ernest Héritte, the French consul, and the above-mentioned Louis Hond, both of whom confirmed Atherstone's assertions ("Diamonds are trumps," April 18, 1867). On April 19, the stone was sent by a steamer named the Celt to London for final verification by Garrard and Co., the Crown Jewellers. On July 12, 1867, Southey received a copy of the certificate that Garrard had issued the preceding month (June 8), which stated that it was a genuine diamond of good quality, slightly colored, and weighed 21.16 ct; they confirmed Dr. Atherstone's value of £500 (Garrard's certificate in Robertson, 1974). A replica of the stone was exhibited at the Paris Exhibition later in 1867. The diamond was subsequently purchased for £500 by Sir Philip Wodehouse, governor of the Cape Colony.

Chalmers' story of the find (little girl Jacobs, children playing with pebbles, Van Niekerk's interest, etc.) was quoted in the influential lecture on the discovery of diamonds in South Africa given by Professor James Tennant at the Society of Arts on November 23, 1870 (Tennant, 1870). Most early writers and, recently, Bruton (1978) follow Tennant's account.

In 1872, O'Reilly gave a different version of the find to Richard Murray, editor of the *Diamond Fields Advertiser* (published in the tent town then called De Beers New Rush, later renamed the city of Kimberley). O'Reilly said that while visiting Van Niekerk in March 1867, he saw Van Niekerk's little girl playing with some bright pebbles. He offered to buy a particularly shiny one, but Van Niekerk gave it to him on the understanding that if it was worth something they would share equally (Murray, 1873). The rest of the story is as told by Chalmers.

**It is strange that Chalmers and Atherstone described the Jacobs/Van Niekerk diamond as a white stone. Hond, in his evaluation in Capetown, mentioned that it had a small yellow spot in one corner ("een geel vlekje," in "Een Kaapsche diamant," April 30, 1867). Garrard's certificate said "slightly colored" without stating which color (most diamonds from South Africa have a faint yellow hue), whereas the Eureka is distinctly yellow.*

***The date on the letter from Boyes is reported in Atherstone, 1869. Atherstone's reply to Boyes was received in Colesberg on April 8. Atherstone determined the specific gravity of the stone, its hardness (it did scratch glass and was not scratched by a hardened steel file), its weight in carats, and its value (probably from the book by Jeffries, 1750, which includes a manual for establishing the value of a diamond from its weight and dimensions). It was a remarkable effort for a self-taught mineralogist who had never before evaluated a diamond.*

In a petition to then-governor of the Cape Colony Sir Henry Barkly, filed January 10, 1872, at De Beers New Rush, O'Reilly claimed to have found (or at least recognized) the first diamond identified in South Africa. Again, he referred to a March 1867 visit to Van Niekerk, but in this account (reproduced in Robertson, 1974, pp. 73–74), he claimed to have picked out the diamond from among Van Niekerk's collection of stones. He offered to buy it, but Van Niekerk gave it to him, saying it belonged to "Daniel Jacobs' little Bushman boy." In an 1876 account, it was in the hands of a little Griqua servant boy who was minding the children (Matthews, 1878). In 1894, O'Reilly changed the little Griqua boy to a little Hottentot boy. In all of these accounts, the rest of the story is as told above.

O'Reilly's claim that he was the first to recognize the pebble's potential was so successful that the first book on the diamond fields (Reunert, 1893), and the most authoritative textbook on gemstones of that era (Bauer, 1896), gave O'Reilly the credit "for establishing the occurrence of diamonds in South Africa." Both publications called the first stone the "O'Reilly Diamond."

An account by a nephew of Van Niekerk given to George Beet in Kimberley states that it was Erasmus Jacobs (figure 5), second son of Daniel Jacobs of De Kalk farm, who found the first diamond (Beet and Terpend, 1917). John Noble, who visited De Kalk, also describes the finder as a young son of Daniel Jacobs, and this version was adopted by Williams (1905). In a sworn affidavit, dated August 9, 1932, Erasmus Jacobs stated that he picked up a bright pebble near the dam on his father's farm, De Kalk, in the summer of 1866 when he was 15 years old (in Robertson, 1974). A Hottentot was standing by but had nothing to do with the discovery. Erasmus gave the stone to his little sister (Riekie). When Van Niekerk was visiting a month or two later, Erasmus and his brother and two sisters were playing games with some pebbles, including the bright one. Van Niekerk acquired it and then passed it on to O'Reilly, who took it to Hopetown and Colesberg.

This account ties up everything very neatly—too neatly, perhaps. The native servant is there (Hottentot, Griqua, or Bushman), but is dismissed as irrelevant; the little girl is there, but she got the stone from Erasmus; and O'Reilly is just the courier. Robertson (1974) commented that the information in the affidavit might have been obtained by "leading questions," that is, by putting words into Erasmus' mouth. Nevertheless, Van Niekerk gets the credit for thinking that the bright pebble might be a diamond.

But how did Van Niekerk get that idea? It may have come from a legend among the Boers that diamonds were collected by Bushmen along the Orange and Vaal Rivers (Dunn, 1871). There are also indications that Van Niekerk had found diamonds even before he recognized the Jacobs diamond ("Jacobs' diamond . . . ," June 4, 1867; "Nelly Jacobs . . . ," July 30, 1867). In the mid-1860s, the government land surveyor, Von Ludwig, often stayed at Van Niekerk's house and the two discussed minerals. When he finished his survey of farms along the Orange River, Von Ludwig gave Van Niekerk a book on gemstones (Beet and Terpend, 1917).

Regardless of who actually found the first stone, it created a mild stir of interest among the Boers (pasturalists of mainly Dutch ancestry) and the Griquas (shepherds of mixed Hottentot/Bushman/Bantu ancestry) living in the general area of the Orange and

Figure 5. Erasmus Jacobs has been credited with finding the first officially recorded diamond on the African continent, on his family's farm, De Kalk, in 1866. This photo was taken around 1907. Courtesy of De Beers.

Vaal Rivers. At least 20 other diamonds turned up during the next two years, found by Griquas and Boers poking around in the gravels of the two rivers (see Chalmers' "list of 20 diamonds" in Weakley, 1869; Atherstone, 1869).

Harry Emanuel, a well-known London jeweler who had written a textbook on gemstones (1865), sent mineralogist James Gregory to South Africa in 1868 to check out the discoveries. During his tour through the Cape Colony, Gregory did not see any rocks resembling the micaceous sandstones and mica schists that had been reported to be the source rocks for diamonds in Brazil (Claussen, 1841). Consequently, he declared that the discovery was "an imposture, a bubble scheme to drive up land values" (Gregory, 1868). He said that if there were any diamonds scattered about, they must have been brought there in the gizzards of ostriches. (Most birds swallow small stones to help their digestive system; he probably added the ostriches as an afterthought, because a few stones as large as several carats were found and offered for sale while he was in the area.)

Gregory's statements created an uproar in the Cape Colony (Atherstone, 1869). Before the debate really took off, though, an 83.5 (old) carat stone (later cut into a 47.69 ct pear shape called the Star of South Africa; figure 6) was offered for sale by the same Van Niekerk who had been associated with the first (Eureka) diamond. This was on March 17, 1869, in Hopetown (L. Hond letter cited in Weakley, 1869). Van Niekerk got the stone from a Griqua shepherd named Swartbooi, who said that he had found it on the Sandfontein farm, which was also near the convergence of the Orange and Vaal Rivers. Van Niekerk gave Swartbooi all he possessed: 500 sheep, 10 head of cattle, and one horse (F. Steytler letter dated March 18, 1869, cited in Robertson, 1974, pp. 173–174). Van Niekerk then sold the stone to Lilienfeld Brothers, general merchants in Hopetown, for £11,200.

This event removed all doubts in the minds of most people in southern Africa, many of whom soon took to searching the sands and gravels of the Orange and Vaal Rivers. Because these early diggers knew little about alluvial mining, the earliest efforts were inefficient, recovering only diamonds of one carat and larger. Hübner (1871) wrote that in 1870 the earliest sieves were made of pieces of corrugated iron sheeting that had been pierced by nails to make holes, so the smallest sieve size was one fifth of an inch (5 mm). Consequently, only rough stones over one carat (about 5 mm in longest dimension) were retained. A year later, metal screens in wooden frames came into use, and screen sizes went down to one-sixteenth of an inch (1.6 mm, about 0.035 ct).

Most of the early diamonds were found in the Vaal River which, in the area near its confluence with the Orange River, flows over amygdaloidal basalt (in fact, andesite). The basalt forms good "trap sites" for diamonds, with rock bars, potholes, and gravel bars. A party of prospectors from Natal, led by a Captain Rolleston, was credited as the first to establish that diamonds not only occur lying on the surface, but also can be recovered by actually digging in the gravel. Their first successful dig was near the German mission station of Pniel on January 4, 1870 ("Captain Rolleston's party finds diamonds . . . ," July 16, 1870; Noble, 1874).*

In the early years, then, the South African diamond fields did not appear to differ much in character from diamond fields in India, Borneo, or Brazil. Diamonds were found in *alluvial deposits*, that is, unconsolidated sands and gravels located in stream beds, flats, and banks, as well as the terraces of rivers. They were recovered by washing and sieving gravels, using picks and shovels and locally made sieves that were often ingenuously combined to make primitive equipment such as rocking cradles. The energy was provided by manual labor; horses and mules were only used for transport.

The First Dry Diggings. In late 1869 and in 1870, however, diamonds were also found in places that were nowhere near an obvious watercourse. They were recovered from reddish loamy surface sand and from yellowish friable calcareous dry mud underlying the red sand. The *yellowground* was later found to overlie harder, compact, bluish gray rock—*blueground*—which eventually was called *kimberlite*. Because they were far removed from any obvious streams or rivers and lacked water during the summer season, people referred to them as *"dry" diggings* in contrast to the alluvial *"river"* or *"wet" diggings*.

Most lay accounts of the history of the South African diamond fields (see, e.g., Dickinson, 1965) state that the Koffiefontein and the Jagersfontein were the first kimberlite pipes discovered, but early correspondence reveals that diamonds were recov-

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**In-house records of the Pniel Mission note the local find of a diamond in 1859. Dunn (1871) mentioned the existence of an 18th-century missionary's map that has the words "here be diamonds" covering part of the Orange and Vaal River areas. Maps of this kind are not rare. The author has seen replicas of "missionary maps" with the words "here be diamonds" in Dutch or Spanish for various parts of the world.*

ered first from the pipes at Dutoitspan and Bultfontein. In July 1870, the foreman of the Jagersfontein farm, a man called De Klerk, found a 50 ct diamond in a small dry creek on that property (Steytler, 1870). I have not found any early records on Koffiefontein. However, Beet (1931) states that the first diamond was found there by a transport rider (the equivalent of today's long-distance truck driver) named Bam, also in July 1870. Both finds were made in small tributaries of the Riet (Reed) River and were first considered river diggings. Yet, in a paper delivered before the Geological Association in London in December 1872 (Paterson, 1873), the statement is made that the Jagersfontein and Koffiefontein workings do not represent alluvial diggings, but rather they are similar to the Dutoitspan diggings, which by that time were already regarded as being other than river diggings.

In fact, in a letter dated November 4, 1869, Fred Steytler wrote that during a visit to Dutoitspan farm the preceding month, he saw hundreds of garnets and some diamonds in limy soil (Robertson, 1974, p. 219). Not only is this several months before the first report of diamonds at Jagersfontein and Koffiefontein, but Steytler's association of red garnets and diamonds suggests that early prospectors had an inkling that the occurrence of garnets was in some way related to the occurrence of diamonds.

Draper (1905) stated that the first diamonds not associated with a watercourse were actually found on Bultfontein farm sometime before November 1869. He claimed that he was present in a small store on the Vaal River on November 6, 1869, when Cornelius Duplooy walked in and showed him a few diamonds that he had found in the mud with which he built his house at Bultfontein. The mud came from the edge of a large pan (i.e., a large shallow depression) named Du Toit's Pan about 25 km (16 miles) east of the Vaal River diggings. Further excavations revealed more diamonds in the small quarry and also at a spot 500 m further north along the edge of the pan, on the neighboring farm owned by Adriaan van Wyk (called Dorstfontein, but once part of the original Dutoitspan farm). These two mud quarries became the two famous diamond pipe mines, Bultfontein and Dutoitspan (figure 7).

Another account states that the diggings on Bultfontein started in September 1869 (report by F. S. Philipson-Stow, cited in Robertson, 1974, p. 221). However, J. B. Robinson, a well-known early digger and diamond buyer, claimed that on his first trip to the Vaal River at the end of 1868, he purchased some pebbles (which he had recognized as diamonds) from Mrs. Van Wyk at Dutoitspan (Murray, 1873).

Figure 6. The 1869 discovery of the large diamond from which this 47.69 ct pear shape known as the Star of South Africa was cut sent many people to the Orange and Vaal Rivers to start digging for diamonds. Photo courtesy of the Central Selling Organisation.

Discovery of the De Beers and Kimberley (the Big Hole) Pipes. These first two dry diggings (Bultfontein and Dutoitspan; Jagersfontein and Koffiefontein were still considered wet diggings in 1870) did not generate much interest, both because the diamonds were small (Higson, 1870) and because living and digging conditions were not very pleasant on the hot, dry plains. Most would-be miners left for the Vaal River in January 1870. Summer was at its height, the water had run out (Babe, 1872), and they had heard of the Rolleston party's success in finding diamonds at Pniel. In May 1871, Richard Jackson and party left the river diggings to check out a rumor and found a lone Boer named Corneilsa (probably Cornelissen, a common surname in Dutch) digging for diamonds in a depression on a farm adjoining Bultfontein and Dorstfontein (Dutoitspan) to the west. This farm—insightfully named Vooruitzigt ("Foresight," or "Expectation")—belonged to two brothers, Johannes

Nikolaas and Diederik Arnoldus De Beer. Because the diamonds at this dry digging were plentiful and relatively large, the place was soon overrun by miners in what came to be known as the De Beers Rush (Williams, 1905).

Two months later, in mid-July 1871, diamonds were found at the foot of a low hill formed of porous calcareous rock, Gilfillan's Kop, which was 3.5 km (2 miles) west of the De Beers Rush. This marked the start of the De Beers New Rush and became the Big Hole (later the Kimberley mine). The credit for this discovery is usually given to the Rawstorne party, originally from Colesberg, who were digging at the original (later "Old") De Beers Rush. One night when the party's cook Damon was drunk and boisterous, the other men sought to get rid of him by telling him to go and dig "on that hill over there." He did, and found a diamond. The hill was proclaimed a public digging on July 21, 1871. It was subsequently renamed Colesberg Kopje (Williams, 1905).

However, Sarah Ortlepp, wife of an Orange Free State surveyor, claimed to have found the first stone by accident while picnicking in the shade of a tree on Gilfillan's Kop a week or two before Damon was told to dig there (this story is first told in Beet, 1931). Gilfillan's Kop was probably the only place for miles around De Beers Rush to have trees and shade for a picnic, as depicted in a Mary Barber watercolor that is now in the Kimberley mine museum. This diamond stayed in the Ortlepp family until recently, when it was placed on permanent loan at the Africana Museum in Johannesburg (J. Hummel, pers. comm., 1995).

A large tent settlement grew up between Old De Beers and De Beers New Rush. On July 5, 1873, this settlement became the town of Kimberley. These two dry diggings, together with Bultfontein and Dutoitspan, fit within a circle 3.5 km across. They developed into the four famous diamond mines located on kimberlite pipes in and around the town of Kimberley: the Kimberley (the Big Hole), De Beers, Bultfontein, and Dutoitspan mines (again, see figure 4). From the earliest days, they produced some spectacular stones (figures 8 and 9).

The dry diggings quickly became far more important than the river diggings. Not only did they contain more diamonds per volume of ground being dug

Figure 7. Dutoitspan, one of the earliest "dry" diggings, was also one of the first to be developed into a pipe mine. Here, in this late-19th-century woodcut, hundreds of miners' tents lie among shallow prospecting pits on the original Dutoitspan farm. The Dutoitspan mine can be seen in the distance. From Williams, 1905.

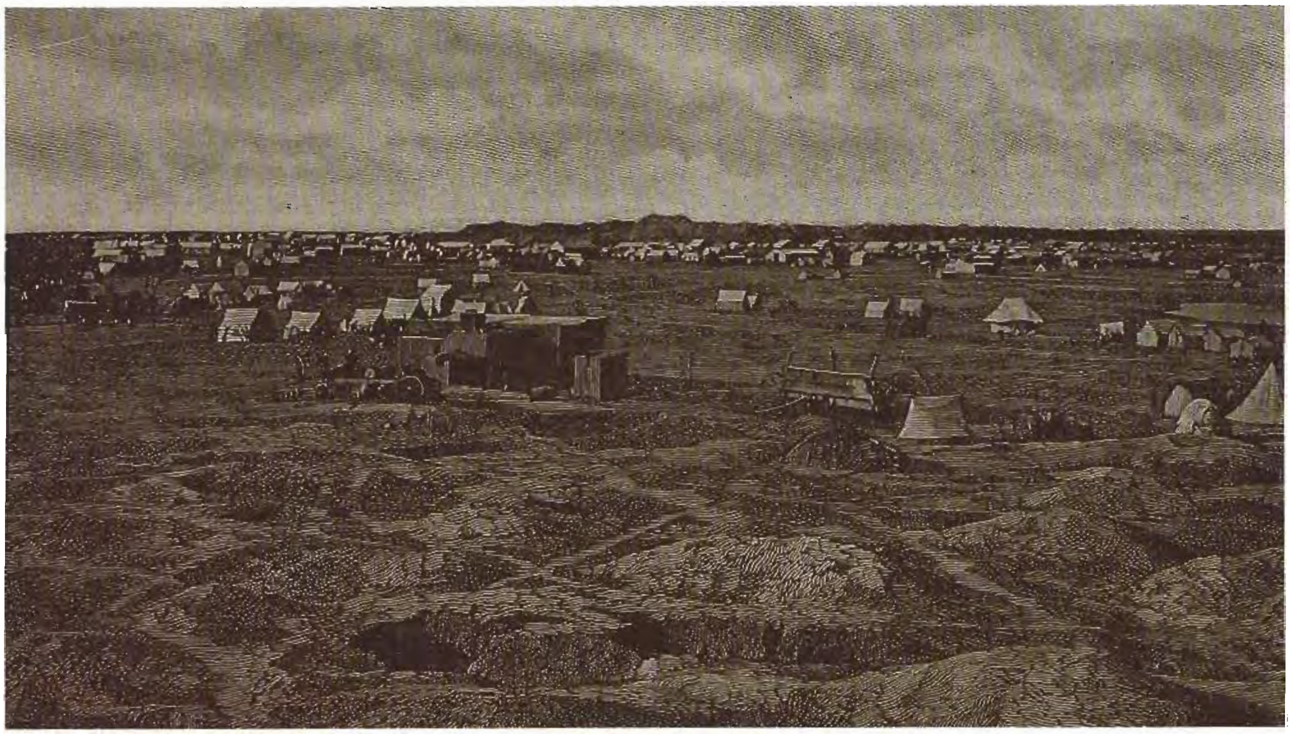


Figure 8. The 55 ct Porter Rhodes diamond (named for the man on whose Kimberley mine claim it was found) was cut from a 154 ct stone considered to be the finest African diamond found up to 1880 (Krashes, 1993). Photo courtesy of Harry Winston Inc.

up, but the fine-grained dry yellowground was much easier to process than the gravels. (Hard "blueground" had not yet been encountered.)

Although as many as 20 other kimberlite pipes were found around Kimberley over the next 20 years, not until September 1890 was another economically successful kimberlite found—no more than 8 km (5 miles) from the Kimberley town center (Williams, 1905). First called the Premier, the name was changed to Wesselton when a larger pipe found in Transvaal in 1903 was also called the Premier.

Consolidation of Claims. In the early days of the dry diggings, individual miners were allowed to register one claim of 31 × 31 feet square. After 1872, when the pits on some claims became deeper than those on adjoining claims, and passageways between them started to fall in (figure 10), two claims were allowed to combine; in 1874, blocks of 10 claims were permitted. Eventually, the friable yellowground ran out and gave way to hard, compact blueground, which was more difficult to work. Gradually, syndicates and small companies bought out the individual miners (Reunert, 1893).

Around 1874, the open pits in the Kimberley mine had reached such depths (about 30–40 m) that mechanization was essential to haul the ore to the surface (see, e.g., figure 11), with mules used to provide the power. Water caused further problems; to pump it out, steam engines made their first appearance in 1875 (Williams, 1905). By 1878, fallen reef (the non-diamond-bearing rock that forms a wall around the pipe) became a very serious problem and cost much money to remove. To raise the necessary capital for mechanization of the mining operation and removal of the fallen reef, the smaller claims were consolidated into major new companies. By 1883, all of the diggings at the Kimberley mine were controlled by a few companies. The most important of these were the Kimberley Central Diamond Mining Company (controlled by Barnato Brothers) and the "French Company" (actually the Compagnie Française des Mines de Diamant du Cap de Bonne Espèrance), which was run by the Rothschild family in Paris. By the end of 1882, the excavations were 120 m (400 feet) deep and underground mining had start-

Figure 9. One of the most famous stones found at Dutoitspan is this 253.70 ct well-formed crystal known as the Oppenheimer diamond, which was recovered in 1964. Courtesy of the Smithsonian Institution.

ed; by 1884, almost all ore at Kimberley came from underground workings (Reunert, 1893).

The De Beers mine was 100 m deep in 1882 and was experiencing the same problems as at Kimberley. In 1880, Cecil Rhodes and his partners formed the De Beers Mining Company and began to consolidate all claims on this pipe into a single entity. De Beers Mining's first technical manager was American mining engineer Gardner F. Williams, who had been manager of an alluvial gold mine near Oroville, California, that had also produced a few hundred small diamonds (Kunz, 1885)! Williams (1886) wrote the first detailed paper on the technical aspects of operating the De Beers mine, which by 1884 had started underground workings. By 1887, all claim blocks in the De Beers pipe had been bought up by De Beers Mining. In the Kimberley pipe, Rhodes's De Beers company first purchased the "French Company" and then, in 1888, bought out Barnato Brothers' "Kimberley Central" to form De Beers Consolidated Mines (Williams, 1905). By 1889, De Beers had completed leasing arrangements for the Dutoitspan and Bultfontein pipes.

Kimberley—the World's Center for Economic Diamond Pipes. As the 19th century drew to a close, many other kimberlite pipes were discovered in South Africa, but they either were not diamondiferous or were low in grade or small in volume. Furthermore, it appeared that the closer the pipes were to Kimberley, the bigger and better they were. Therefore, Kimberley was considered the world center for economic kimberlite pipe mines (C. Rhodes, quoted in *De Beers Annual Report*, 1896). The discovery of the first Premier (later called Wesselton) pipe in September 1890, less than 8 km from Kimberley, seemed to confirm this view. Eventually, all five economic pipes around Kimberley, plus the Jagersfontein and Koffiefontein pipes in the Orange Free State, were either owned, leased, or gradually purchased by De Beers Consolidated Mines, which controlled the output of all economic diamond pipes in South Africa by the turn of the century. (The purchase of all shares in Koffiefontein was completed in 1911.)

Figure 10. By 1872, as this early photo shows, the walls between pits at the Kimberley mine had started to collapse, so new mining laws allowed two claims to combine. By 1874, blocks of 10 claims were permitted. Photo from Williams, 1905.

Discovery of the Premier Pipe. The Kimberley area's dominance of diamond production in South Africa changed in 1903 when the large Premier pipe was discovered 30 km east of Pretoria, the capital of the Transvaal—500 km northeast of Kimberley. Alluvial diamonds and a few small pipes had been found in the general area as early as April 1897 (Molengraaff, 1897), but the Boer War (1899–1902) halted prospecting activities. By 1898, Thomas Cullinan, a builder and local brick manufacturer from Pretoria, had recognized that alluvial diamonds found on the Bijenestpoort (Beehive Pass) farm came from the adjoining farm to the east, Elandsfontein. A diamond was actually found right beneath the wires of Elandsfontein's western fence (Helme, 1974). Elandsfontein's owner, Prinsloo, would not sell and threatened to shoot any diamond prospectors trespassing on his farm. Nevertheless, in November 1902, after Prinsloo's death and the end of the Boer War, Cullinan was able to purchase the farm from Prinsloo's widow and heirs for £52,000 (Helme, 1974).

In January 1903, Cullinan's prospecting pits revealed diamondiferous kimberlite ("Premier . . . ," 1903), early evidence of a very large, 32 ha (79 acre) diamondiferous kimberlite pipe ("The Premier mine . . . ," 1903; Merensky, 1904). Although a De Beers geologist sent to inspect the discovery in January 1903 reported (to their relief) that it was a "flash in the pan" (Helme, 1974, pp. 54–56), his assessment proved very wrong when the largest stone ever found—the Cullinan diamond, at over 3,024 (old) carats (3,106 metric carats)—was recovered there January 25, 1905 (Molengraaff, 1905). Other large stones have since been found at the Premier mine, which proved to be a strong competitor in overall production to the De Beers mines (see "History of Diamond Production" in Part II). Thomas Cullinan went on to serve as Chairman of the Premier (Trans vaal) Diamond Mining Company (Liddicoat, 1993; figure 12). Not until 1920 did the Premier's board of directors reach an understanding with De Beers on levels of production. In 1922, De Beers finally acquired all shares in the Premier mine ("De Beers issuing . . . ," 1923, p. 70). The Elandsfontein area continued to produce many important alluvial diamonds, including the 726 ct Jonker and 287 ct Pohl diamonds, both found in 1934.

Underground Mining. The Kimberley and De Beers mines became the first underground diamond-mining operations in 1882 and 1884, respectively, when workings reached depths of 120 m (400 feet). By the time the Kimberley mine was closed in 1914, it had been worked down to 1,098 m. The De Beers mine was closed in 1908; it was re-opened in 1963 as a modern underground mine, and was closed again in November 1990, when workings had reached 720 m (*De Beers Annual Report*, 1990). A gradual transition from open-pit to underground mining took place in the other three diamond pipe mines around Kimberley—Bultfontein, Dutoitspan, and Wesselton (figure 13) from 1906 to 1910, when depths from 120 to 150 m were reached.

The Jagersfontein mine was worked both open pit and underground until 1932, and then again as an underground mine from 1949 until 1971. The Koffiefontein mine remained open pit until its closure in 1931. It was re-opened as an open-pit mine in 1971, converted to an underground mine in 1977, closed again in 1982, and re-opened in 1988; it is still active today (*De Beers Annual Reports*, 1971 to present). The Premier mine (figure 14), closed in 1932, was re-opened as an underground mine in 1946, and is still active. It is the source of many superb stones, including the 426.50 carat piece of rough from which the 128.25 ct D-flawless Niarchos was cut as well as the 599 ct rough that produced the 273.85 ct D-internally flawless Centenary diamond (figure 15). The Finsch mine started as an open-pit operation in 1966 and was converted to underground mining September 1990, after the pit reached a depth of 430 m (*De Beers Annual Reports*, 1966 and 1990).

Currently, the only operating underground diamond mines are in South Africa. All other diamond pipe mines worldwide are open pit.

Fissure Mines. As early as 1895, narrow fissures (actually dikes, but called fissures in South Africa)—50 cm to a few meters wide and several kilometers long—and related small pipes or "blows" (local widenings of a fissure), were known in the Orange Free State (Molengraaff, 1895) and in the Cape west of Kimberley. From 1905 on, intermittent mining took place at Driekoppies (New Thor, Phoenix) and Roberts Victor, New Eland, and Monastery (a small pipe) in the Orange Free State, as well as at Frank Smith-Weltevreden, Sover-Mitjemanskraal, Newlands, and Leicester (a small pipe) in the Cape. All these mines were closed temporarily during the periods 1914/15, 1921/22, 1932/34, and 1940/44 (see "History of Diamond Production," in Part II) and for several periods during more recent times when demand for new mine production decreased.

Figure 11. As the mining claims in the Kimberley area consolidated and pits got deeper, mechanization was needed to bring the miners to the ore and transport the ore to the surface. Photo from Williams, 1905.

In 1958, high-grade, good-quality fissures were found at Bellsbank/Bobbejaan, 80 km northwest of Kimberley. These have been successfully mined intermittently since then (figure 16). During the last decade, most of the fissure mines and small pipes have been re-opened, with a combined (non-De Beers) production that the author has calculated to be as high as 200,000 carats per year. Most of these are underground mines.

The Lichtenburg Gravels. From the 1880s on, alluvial diamonds were found farther and farther upstream from the original Vaal River diggings (Coe, 1904). By

Figure 12. This necklace, which has a 2.60 ct blue diamond as its center stone, was a present from Premier mine Chairman Thomas Cullinan to his wife, Annie, in celebration of the gift of the Cullinan diamond to King Edward VII of England in 1902. Courtesy of S. H. Silver. Photo © Harold & Erica Van Pelt

the turn of the century, diggers had reached Bloemhof (again, see figure 4). During 1907–1911, diamonds were discovered in a thin layer of gravels well away from the northern bank of the river, on Mooifontein farm (Harger, 1911). In 1922, diamonds were found in gravels on Sterkfontein farm in the headwaters of the Mooi River, a northern tributary of the Vaal ("The Sterkfontein diamond diggings," 1923).

Then, in February 1926, the first diamonds were found near Lichtenburg, on the high, flat plateau that forms the watershed between small, south-flowing streams draining to the Vaal River and north-flowing streams draining to the Limpopo River (Williams, 1930). Large concentrations of diamonds (several million carats each) were found at several places in large holes in the limestone plateau. Filled with red sandy soil and coarse river gravels, the holes had no obvious watercourses to connect them. Some people believe that there is a kimberlite pipe beneath each hole (B. Von Gottberg, pers. comm., 1982), but the consensus is that the holes are the remains of an old river system since eroded (see, e.g., Williams, 1930).

Each diamond deposit on the plateau was thrown open to the public by an organized "rush." A Transvaal government official stood on a cart and read a proclamation declaring a farm, or part of it, open for diamond digging. At the drop of a flag, thousands of diggers ran forward to put their claim pegs in the ground. An estimated 25,000 diggers participated in the largest of these rushes, on February 25, 1927, at Grasfontein ("Grasfontein diamond rush," 1927).

The Lichtenburg gravels were described at length by Gardner Williams's son, A. F. Williams (1930), who was general manager of De Beers Consolidated

Mines from 1904 to 1931. At the height of mining, in 1927, the gravels produced 2 million carats of diamonds. Although activity has dropped off dramatically, the field is still worked sporadically.

Namaqualand Coast. Diamonds were discovered in coastal deposits, actually dune valleys, near Lüderitz in South West Africa (now Namibia) in April 1908 (figure 17; see below). In August 1925, amateur prospector Jack Carstens found the first diamond on the coast south of the Orange River, in South Africa, near Port Nolloth (Reuning, 1928; Carstens, 1962). The area was soon overrun by amateur prospectors as well as some professional geologists, such as Hans Merensky and Ernst Reuning.

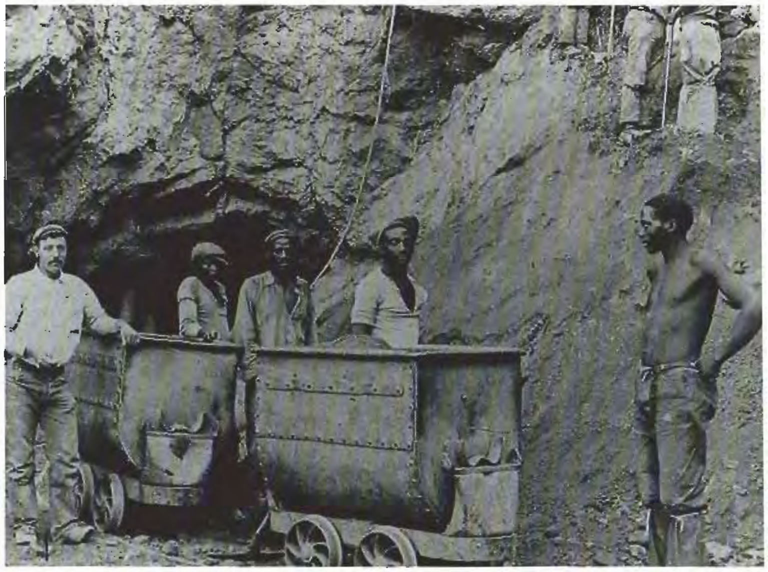
Merensky was famous for discovering the platinum-bearing horizon that bears his name ("Merensky Reef") in Transvaal Province (Lehman, 1955), and Reuning had much experience with the coastal diamond deposits in South West Africa. In January 1927, Merensky discovered the "oyster line" in the Alexander Bay region. He found that the diamonds in this area are associated with a raised beach terrace (a terrace formed when sea level was higher than at present), which also contained many oyster shells (Wagner and Merensky, 1928). He pegged his now-famous oyster line and formed the H. M. Syndicate.

The sudden increase in diamond production due to the Lichtenburg discoveries, combined with the richness of the Namaqualand coastal deposits, caused the South African government to pass the Precious Stones Bill in November 1927—forbidding further prospecting and digging for diamonds on state-owned land in Cape Province (Kunz, 1929). However, the H. M. Syndicate was awarded its discovery claims (a prospector who finds a new pipe or alluvial deposit is awarded two claims), and mining started in 1928. The remainder of the oyster line was taken over by the South African government and proclaimed the Alexander Bay State Alluvial Diggings ("Government intends . . . ," 1928). In 1930, the State Alluvial Diggings acquired all the discovery claims in the area, including those of the H. M. Syndicate. They were partly privatized in 1989 into the new Alexander Bay Development Corp. ("Alexcor"), which has since been granted three sea concessions.

Other important diamond deposits were discovered in 1926 at the mouth of the Buffels River at Kleinzee. They were also exempt from the prohibitions of the Precious Stones Bill, because the area was a freehold property. Johannesburg jewelers G. S. Ronaldson and J. van Praagh, who had bought the property, invited the Consolidated African Selection Trust (CAST), a diamond mining company in the Gold Coast (now Ghana) to evaluate the deposit. CAST's prospectors, George and Ronald Dermody, two brothers originally from Ireland, submitted a favorable report (Selection Trust in-house reports). To develop these deposits, the Cape Coast Exploration Company was incorporated in January 1928. CAST originally obtained nearly a third of the shares, but Anglo American and Barnato Brothers had bought out everyone by January 1939 (Greenhalgh, 1985). Systematic mining started in 1929, was suspended in 1932, and resumed in 1937. The Kleinzee deposit was mined out in 1958, but adjoining deposits to the north at Tweepad and Dreyerspan and to the south at Annex Kleinzee are still being worked.

The Precious Stones Bill was rescinded in 1960. By then, De Beers had purchased almost all the farms (and their mineral rights) along the Namaqualand coast from near Port Nolloth south to the mouth of the Olifants River, a distance of 320 km (200 miles). These areas were mapped and prospected in 1958 and 1959 (the author participated in these surveys as his first job), and in the early 1960s several minable reserves were outlined along the coast at Koingnaas and Hondeklip Bay. Mining started at Koingnaas in 1978 ("Koingnaas alluvial diamond mine . . . ," 1978) and is still ongoing. De Beers and Transhex are

Figure 13. Once depths of 120–150 m were reached, mining companies at pipes like the Wesselton (shown here) had to go underground.



presently mining at Hondeklip Bay. Minable reserves were also located at Langhoogte in ancient river terraces along the Buffels River, the largest of the dry river beds that are common along the Namaqualand coast. Mining started there in 1978 and is still ongoing.

In 1966, Baxter Brown and Hugh Jenner-Clarke were the first to discover alluvial diamond deposits in fossilized channels (earlier courses, bends, or meanders that are now covered by terrace sands and gravels of the present river bed) in the lower course of the Orange River's south bank (Wilson, 1972). These deposits became the Ochta mine and Baken Diamante, which produced large, good-quality stones. Other fossilized channels have since been found on the north bank.

Off-Shore Deposits. Texas oil man Sam Collins formed the Southern Diamond Corporation in 1961 to prospect for and eventually mine diamonds from the sea floor off the coast of Namaqualand. De Beers took over management of Southern Diamond in 1964. Although prospecting and research have continued, there has as yet been no systematic mining operation.

The South African government has divided the sea concessions into 14 blocks, further subdivided into zones A (tidal), B (shallow), and C (deep sea), as illustrated in Gurney et al. (1991). Several junior mining companies (notably Benguela Concessions) recover diamonds from submerged beaches in tidal zone A, operating from the shore. Divers supported by long air hoses guide powerful suction devices that transport gravel and sand to the beach where they are washed and sorted. In zone B (shallow sea), small boats are also used, but such operations frequently have to be suspended because of rough seas (Gurney et al., 1991).

Figure 14. The Premier mine, here shown in an early-20th-century photo, was mined open pit until it closed in 1936. Reopened in 1946 as an underground mining operation, it is still being actively worked. Photo courtesy of De Beers.

Discovery of the Finsch pipe. In 1963, De Beers purchased a large pipe prospect from Alastair Fincham and Wilhelm Schwabel, who named their find Finsch after the first three letters of their surnames. Because of the 1927 Precious Stones Bill, the prospect was first pegged as an asbestos claim in 1958. When this law was repealed in 1960, the prospectors started to work their claim for diamonds and offered it to De Beers. The latter declined the offer on the advice of one of their geologists, who had gotten uneconomic results from a bulk sample collected in one large deep pit. The prospectors then dug a long, shallow trench right across the pipe and found patches of high-grade kimberlite (author's own files). De Beers later agreed to pay 4.5 million Rand (about US$4 million) to purchase this 17.9 ha (44 acre) pipe ("Finsch Diamonds (PTY) Ltd. acquired by De Beers," 1963). Finsch came into production in 1966 and was officially opened February 27, 1967. It soon produced 3 million carats per year. Finsch became an underground mine in September 1990, when a depth of 430 m was reached (figure 18).

Discovery of the Venetia Pipe. Although one would think that South Africa had been thoroughly prospected over the years, a whole new field of diamondiferous kimberlites was recently discovered in the northern Transvaal. In the mid-1970s, while prospecting for copper on the Venetia farm, Saturn Mining (a subsidiary of the Anglo Vaal group) and African Selection Trust intersected a small kimberlite fissure in one drill hole (Selection Trust in-house reports). De Beers acquired a lease from Saturn Mining to prospect for kimberlites, and in 1979/1980 De Beers geologists found 12 pipes. The Venetia mine, on the largest of the pipes (12.7 ha [31 acre]), started production in 1991 and was officially opened August 14, 1992. It reached its planned production of 5 million carats per year in 1993, and is scheduled to produce this amount annually for the next 20 years.

Future Prospects. The discovery of the Venetia pipe, which came more than 100 years after the original kimberlite discoveries around Kimberley, showed that new, important, economic pipes can still be found in South Africa. Diamondiferous fissures may still await discovery in the central part of the Orange Free State, the eastern and western Transvaal, and the northern Cape areas. It is also possible that a large pipe, covered by soil or calcrete, could be found in an area that is difficult to prospect. Thus, although the country has been prospected for a long time, there is still hope for new economic discoveries.

LESOTHO
(Formerly Basutoland)

The first concession to prospect for diamonds in Basutoland (now Lesotho) was granted by the Basuto paramount chieftainess to Colonel Jack Scott in 1954 ("Colonel Jack Scott . . . ," 1978). Several kimberlite occurrences were described in the first official report on the geology of Basutoland (Stockley, 1947), but it was specifically stated that none had yet been found to contain diamonds.

In 1959, De Beers geologists joined Jack Scott's prospectors and two post-graduate students, Barry Dawson and Peter Nixon, from the newly formed Research Institute for African Geology at the University of Leeds, England, where the first modern research on kimberlites was started (Dawson, 1962; Nixon et al., 1963). De Beers withdrew in 1962, and the Kao and Letseng-la-Terai pipes (found in 1954 and 1957, respectively) were declared public diggings. A large, pale brown 601.26-ct stone was found in the Letseng pipe in May 1967, and in 1968 RTZ took over prospecting and evaluation of the Kao and Letseng pipes. Notwithstanding the occasional finds of large diamonds, RTZ concluded that the pipes were not economic and withdrew in 1972.

De Beers, however, negotiated an agreement in 1976 to reinvestigate the 15.9 ha Letseng pipe, located at 3,000 m altitude in the Drakensberg Mountains. When mining started in 1977 on a 3.7 ha (9 acre) section, Letseng became the highest diamond mine in the world ("Lengthy wait . . . ," 1978). The mine closed in October 1982.

SWAZILAND

Although a diamond find was reported in 1895 from Mahash in the Lebombo Range ("Diamonds found near Mahash . . . ," 1895), it was not confirmed. After De Beers geologists found the alluvial Hlane diamond deposit in 1973, they traced the origin of the diamonds to the small, 2.8 ha (6.9 acre) Dokolwayo pipe in 1975 (Hawthorne et al., 1979). De Beers ultimately decided that both the diamonds and the pipe were too small to sustain a substantial mining operation. However, in 1983 Transhex started a mine that is still active, producing about 50,000 carats per year.

Figure 15. Many superb diamonds have recently come from the Premier mine, including the 599 ct diamond from which this 273.85 ct D-color (internally flawless) Centenary diamond was cut. Photo courtesy of De Beers.

NAMIBIA
(Formerly South West Africa)

Namibia has been a steady producer of small but good-quality diamonds since the early 20th century. In fact, today it ranks first in the world in value per carat. Virtually all of the diamonds found are recovered from raised beach terraces and, in recent years, from near-shore and even ocean-floor deposits.

First Discoveries in 1908. The first alluvial diamonds were found in April 1908 by railway worker Zacharias Lewala, near Kolmanskop (Merensky, 1909; Levinson, 1983). Diamonds occurred in loose sand in valleys between the dunes along the coast from Lüderitz to Bogenfels, 100 km to the south (again, see figure 17). The mining settlements of Kolmanskop and Elizabeth Bay were founded in 1909.

Some areas were so rich that the workers had only to crawl along the sand to pick up diamonds (Kaiser, 1926). Security must have been a nightmare. The deposits yielded large quantities of small diamonds of very good quality, and by 1912 South West Africa had captured 12% of world production by volume (Wagner, 1914). Surface mining continued until World War I intervened. In 1915, the country was occupied by South Africa and ownership of the mines was transferred to the Custodian of Enemy Property.

Birth of CDM in 1919. After the war, Consolidated Diamond Mines of South West Africa (CDM, created specifically for this purpose by Ernest Oppenheimer) took over, reorganized, and purchased the properties of the various German companies. (In 1917, Oppenheimer had formed the Anglo American Corporation of South Africa [AAC] to raise venture capital for investment in the Witwatersrand gold mines; AAC took a large shareholder position in CDM in 1920.) Mining of the Kolmanskop and Elizabeth Bay areas resumed through the 1920s and 1930s, but in 1928 diamondiferous marine terraces (raised beaches) were found in the areas north of the mouth of the Orange River ("Another great diamond discovery," 1928; Kunz, 1929). The terrace diamonds were much larger (average about 1.5 ct) than the small diamonds found at Elizabeth Bay and Kolmanskop (average from 6 to 7 stones per carat), and they were of equal or better quality. Thus, most mining operations had shifted to the latter area by 1935, and by 1939 the settlements at Kolmanskop and Elizabeth Bay had been abandoned.

Figure 16. Some small dikes, like this "fissure" at Bellsbank (known as the Bobbejaan), have also been mined successfully.

Oranjemund. CDM headquarters moved from Lüderitz to the new township of Oranjemund (Orange mouth = mouth of the Orange River) in 1943. In this area, diamonds are found in sands and gravels of ancient marine terraces. These occur up to 35 m above present sea level and are covered by an overburden of dune and beach sand as much as 12–15 m thick (Hallam, 1964; Murray et al., 1970). Huge earth-moving machinery is used to remove the overburden.

Offshore and Foreshore Mining. In the early 1960s, the idea emerged that diamonds would also be found in submerged marine terraces farther out to sea. In 1961, Sam Collins formed Marine Diamond Corporation ("Diamonds mined off the seabed," 1962) and obtained a sea-mining concession. Marine Diamond worked the sea floor near the coast from October 1961 to July 1963, producing 51,000 carats. However, unpredictable weather, rough seas, inadequate technology and prospecting, and excessive capital expenditures prevented financial success.

In 1963, CDM purchased 29% of Marine Diamond and agreed to incorporate CDM's diamond-mining rights to the tidal zone into a new sea-mining joint venture. After initiating a large-scale prospecting and underwater-mining research program, in 1967 CDM leased the marine diamond mining rights from Collins's company. In the meantime, in 1965, CDM had begun foreshore mining in the shallower parts of the tidal areas by building groynes (rigid structures built out from the shore) using old metal bedsteads and canvas sheeting to keep back the sea (Borchers et al., 1970). Although operations were suspended in April 1971, they resumed in 1973 with new, improved methods (still in use today) by which huge sand walls are pushed up to 200 m from the shore, and once-submerged terraces are mined down to about 20 m below sea level (figure 19).

Submarine Mining. After several years of research and prospecting, actual sea-bed mining operations started in 1991 in Namibian waters as deep as 100 m. Although first-year production was modest—about 125,000 carats—by 1994 diamond production from submarine deposits already accounted for 31% of Namibia's total production (*De Beers Annual Reports* for 1991 to 1994).

These deposits are believed to extend to the edge of the continental shelf (up to 100 km from the shore) in water over 100 m deep, so mining costs will be high. However, the quality of the diamonds recovered is exceptionally good and the deposits are huge (Gurney et al., 1991; Meyer, 1991).

New Mines. CDM has also opened two new mines on land in recent years: Elizabeth Bay, on the coast, 30 km south of Lüderitz; and Auchas, on the north bank of the Orange River, 45 km inland. Elizabeth Bay's ore reserves have been calculated at 38 million tonnes at 6.6 carats per 100 tonnes, that is, more than 2.5 million carats of good-quality small stones (Boting and Russel, 1993). The mine, started in June 1991, is projected to produce 250,000 carats annually for 10 years.

Reserves at the Auchas mine are 12.3 million tonnes of ore (under 45 million tonnes of sandy overburden), with 3.6 carats of diamond per 100 tonnes (Croll and Cooper, 1993). Plans are for the mine, started in July 1990, to produce 45,000 carats of good-quality, larger-than-average diamonds annually for 10 years.

CDM Becomes Namdeb. After intense negotiations, CDM was restructured in November 1994 as a new company, Namdeb Diamond Corporation (Namdeb), owned in equal shares by De Beers Centenary and the Namibian government (see, e.g., "Namibia: The government is . . . ," 1995, and "Namibia: De Beers . . . ," 1995).

Kimberlites. The first kimberlite in Namibia was discovered at Gibeon Village in 1889. By 1906, several other occurrences had been identified as far as 50 km east of Gibeon, near Mukorob, and 85 km south of Gibeon, near Brukkaros (Scheibe, 1906). The site "near Brukkaros" where a 2.75 (old) ct diamond was allegedly found in 1893 could not be confirmed, and the kimberlites in the Gibeon field proved to be barren (Janse, 1975). Namibia has at least four other kimberlite fields, but all proved to be barren.

BOTSWANA

(Formerly Bechuanaland)

Botswana is the second largest diamond producer by volume on the African continent, and the largest producer by total value in the world. Diamonds are recovered from two of the largest-known kimberlite pipes—Orapa and Jwaneng—and one small one, Letlhakane (figure 20). There is no production from alluvial sources. These kimberlite pipes were discovered only relatively recently, because a large part of the country is covered by a thick layer of desert sand.

Figure 17. This map shows the key areas where diamonds are being mined in on-shore and off-shore deposits along the coasts of Namaqualand (in South Africa) and Namibia. The broken line above the Orange River in Namibia represents the outer boundary of the restricted diamond area. The inset shows the outline of Namibia.

Early Discoveries. Although earlier finds of alluvial diamonds had been rumored (Wayland, 1949), the first officially recorded discovery—of three small diamonds (0.27, 0.14, and 0.02 ct)—was made in the Motloutse River near Foley in 1959, by a prospecting party led by Humphrey Willis of CAST/Selection Trust (Boocock, 1960, 1965). The diamonds could not be traced to a host kimberlite; rather, they were believed to come from an intermediate host, a conglomerate of the Ecca series (Selection Trust in-house report), and the company allowed their lease to lapse.

Discovery of Orapa. Most of central Botswana is covered by the Kalahari Desert, a vast expanse of red sand dunes that lie in long rows separated by valleys covered in grass, bushes, and clumps of thorn trees, but no surface water. The De Beers subsidiary Kimberlite Searches started prospecting in 1955 in

Figure 18. The Finsch mine has been a major South African diamond producer since it was opened in 1967. Mining went underground when the pit—shown here in September 1990—had reached a depth of 430 m.

the eastern (less sandy) parts of the country, and in 1965 they found two nondiamondiferous pipes near Mochudi (Boocock, 1965). After 1960, they had also moved into the Motloutse River area, farther west than CAST had prospected. In April 1967, 12 years after they had started, they found a large diamondiferous kimberlite pipe near a cattle post called Orapa (figure 21). The De Beers prospecting teams (then called De Beers Prospecting Botswana) were directed by Dr. Gavin Lamont, with Jim Gibson the regional team leader. The actual discovery of the Orapa pipe, however, was made by Manfred Marx, a junior geologist ("Young prospector . . . ," 1969; "How the Orapa pipe was discovered," 1971). Marx said to me once that "everyone has one great piece of luck during their lifetime of prospecting, and I had mine in my very first job" (pers. comm., 1994).

Orapa turned out to be a pipe topped by an oval-shaped crater 1,560 m × 950 m and about 80 m deep. At 106.6 ha (263 acre), it was the world's second largest economic kimberlite (after the 146 ha of Tanzania's Mwadui pipe).

Bechuanaland became the independent state of Botswana in 1966, and in 1969 De Beers Botswana Mining Company (Debswana) was registered in Gaborone to develop Orapa, originally as an 85/15 joint venture of De Beers and the Botswana government. The Orapa mine started production in July 1971 and opened officially on May 26, 1972, with a planned production of 2.5 million carats per year ("Orapa opening . . . ," 1972; Allen, 1981). In 1975, the joint venture was reorganized on a 50/50 basis, and the principals decided to double the size of the Orapa operation. Orapa reached a peak production of 6 million carats in 1991, and produced 5.4 million carats in 1994 (*De Beers Centenary Annual Reports* for 1991–1994).

Figure 19. By building huge walls of sand to keep back the sea, CDM has mined vast tracts in Namibia that were once the sea floor. Photo courtesy of De Beers.

Discovery of Letlhakane. The Orapa pipe is part of a field that contains 30 known kimberlites. One year after Orapa was discovered, De Beers Prospecting found two small pipes, Letlhakane 1 and 2 (11.6 and 3.6 ha, respectively), about 48 km southeast of Orapa. These two pipes came into production in 1976 at a projected annual rate of 300,000 carats (Allen, 1981); in 1994, they produced 1.1 million carats (*De Beers Centenary Annual Report* for 1994).

Discovery of Jwaneng. After the successful discoveries of Orapa and Letlhakane, De Beers ventured south into the Kalahari Desert and in 1973 discovered the Jwaneng pipe. Eleven pipes were eventually found 25–60 m under a cover of Kalahari sand. Jwaneng forms three lobes—south, central, and northeast—with a combined area of 54 ha (133 acre) under 50 m of sand. Mining started in the central, 27 ha lobe (figure 22) in February 1982, at a planned annual production rate of 5 million carats (Chadwick, 1983); in 1994, Jwaneng produced 9 million carats.

Prospecting by Falconbridge and Others. In 1974, a Falconbridge/Superior Oil joint venture began prospecting in Botswana combining indicator-mineral sampling with aeromagnetic surveys (which will be described in detail in Part II). Over the next five years, they found approximately 60 kimberlites under 20–60 m of sand. Although one of these pipes, the Gope 25, appeared to have potential, none of these kimberlites has yet proved economic.

In 1982, Superior Oil withdrew and Falconbridge formed two joint ventures with De Beers: Gope Exploration, to develop Gope 25; and Debridge Exploration, to investigate other areas (Jones, 1982). No economic discoveries have been announced to date.

Since 1988, smaller companies based in Australia, Canada, and South Africa have joined the search for diamonds. As of 1994, at least 140 kimberlites in 11 clusters or fields were known. Except for Orapa, which outcrops (again, see figure 20), all other kimberlites in Botswana lie under 20–100 m of sand. No new major discoveries have been announced thus far, but it is highly probable that at least one more significant diamond pipe mine will be found.

ZIMBABWE
(Formerly Southern Rhodesia)

Historically, Zimbabwe has been a small producer of diamonds from alluvial and minor kimberlite deposits. Today, the River Ranch mine, a single pipe, appears to be economic. Because the geologic framework of Zimbabwe favors kimberlite intrusions, it has been the object of considerable prospecting activity in recent years.

Figure 20. The key mines in Botswana are the Orapa, Jwaneng, and Letlhakane. The first of these, the Orapa pipe, was discovered only in 1967. The Gope 25 pipe is still being evaluated.

Alluvial Deposits. H. R. Moir, who had dug diamonds at Vaal River, was the first to discover alluvial diamonds in the Somabula Forest area, in 1903 (Mennell, 1906; Macgregor, 1921). By arrangements made in 1892 with the British South Africa Company (founded by Rhodes), De Beers had an exclusive license to mine all minerals, including diamonds, in Rhodesia. Therefore, Moir contacted prominent entrepreneur Sir James Willoughby, who formed the South African Options Syndicate and used his influence to obtain a diamond-mining concession from De Beers. Mining operations started in 1905 but seldom amounted to more than a few hundred carats annually; they finally ceased in 1938.

Kimberlite Pipes. The first kimberlite pipe, Colossus, was found in 1907, about 80 km southwest of Gwelo (Mennell, 1908), but it was less than colossal—only 900 by 150 m. Several smaller pipes were later found nearby, but all proved to be uneconomic.

De Beers geologists found more kimberlites in the central part of the country in the late 1930s, but the results were not encouraging. Kimberlite Searches has prospected intermittently since the

Figure 21. This aerial view shows the Orapa kimberlite pipe shortly after its discovery in 1967. Unlike most kimberlites, the circular outline of the pipe (lower right foreground) can be seen at the surface. Photo courtesy of Manfred Marx.

early 1950s, adding to the number of uneconomic kimberlites discovered.

Since 1992, however, prospecting activities have accelerated due to a change in the mining law and the promise of continued political stability, combined with discoveries of diamondiferous pipes in Canada's Archaean shield (an area of ancient granitic rocks, i.e., more than 2,500 million years old). Most of Zimbabwe is also underlain by an Archaean shield, but the overlying platform sediments have been eroded from much of it. Therefore, large pipes and craters are less likely to occur here than in Botswana and South Africa (where the platform sediments are still present, so the upper, wider parts of pipes and craters could still be preserved). Nevertheless, several Canadian and Australian companies, as well as Kimberlite Searches, are actively prospecting throughout the country ("Zimbabwe diamond hunt expands," 1994).

About 30 kimberlites had been found in Zimbabwe as of mid-1995. To date, only the River Ranch pipe has proved economic.

Figure 22. Botswana's enormously successful Jwaneng open-pit mine, here as it looked in 1992, produced 9 million carats of diamonds in 1994. Photo courtesy of De Beers.

River Ranch Mine. The River Ranch kimberlite pipe was found in 1975 by Kimberlite Searches, but was reported to be uneconomic (*De Beers Annual Report* for 1977). The mineral rights were returned to the state and were then acquired by a joint venture between Auridiam (Australia based) and Redaurum (Canada based). They started a mining operation in 1992 with a planned annual production of 300,000 carats; as of the end of 1994, however, production was a little over 150,000 ct (Holloway and Associates, 1995). Evidence for the presence of very large diamonds is provided by the finding of large fragments from diamonds broken during recovery. Fragments of one large stone added up to 326 ct. The plant has been modified to recover large stones—up to 40 mm in longest dimension—intact ("Further evidence . . . ," 1994). The mine was officially opened November 2, 1995.

ZAIRE
(Formerly the Belgian Congo)

In recent years, Zaire has been the largest diamond producer in Africa (and second in the world after Australia) by weight, nearly 70 million carats during 1991–1994. Although most of the diamonds are recovered from sands and gravels along watersheds and hillsides, the highly productive Mbuji-Mayi area derives large quantities of poor-quality stones from small kimberlites. However, the outlook for diamond mining in Zaire is currently uncertain, because of chaotic social and political conditions.

Earliest Discoveries. The earliest diamond find was made in December 1903 in Katanga (now Shaba Province) by two tin prospectors, Cookson and Jacks, who were working for Tanganyika Concessions, an English tin company. They found the first diamond in Mutendele Creek, a tributary of the Lualaba River, one of the headwaters of the Congo (now Zaire) River (Buttgenbach, 1925). Further minor discoveries made in the Lualaba River during 1906 to 1909 (Ball, 1912) were traced to two groups of diamondiferous, but uneconomic, kimberlites along the eastern and western rims of the Kundelungu Plateau. Although some of the pipes were large (such as Talala, at 50 ha), grades were low, less than 0.1 ct per tonne, and the diamonds were very small, averaging 15 stones per carat (Bardet, 1974).

Instead, the major diamond deposits in the Belgian Congo were found in two areas 350 km apart: Tshikapa in Western Kasai, and Mbuji-Mayi in Eastern Kasai Province (figure 23).

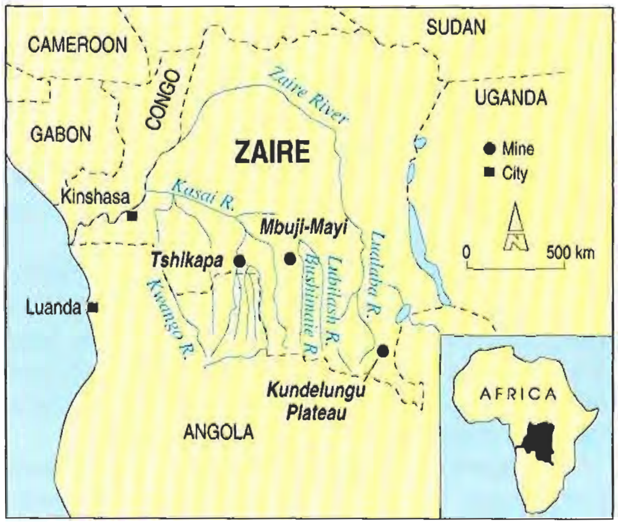


Figure 23. Although some uneconomic pipes have been found along the eastern and western rims of the Kundelungu Plateau, the major diamond deposits in Zaire are in the region of the towns of Tshikapa and Mbuji-Mayi.

Tshikapa. Belgian prospector Narcisse Janot found the first diamond—0.1 ct—in the Tshikapa area on November 4, 1907, in the Kasai River at Mai Munene (Ball, 1912). He was a member of a field party led by American geologist M. K. Shaler, which was prospecting for the newly formed Société Internationale Forestière et Minière du Congo (Forminière), a joint venture between (first King Leopold and then) the Société Generale de Belgique and the American Guggenheim-Thomas Ryan group.

The Tshikapa area was inhabited by the fiercely independent Batshioko tribes, which resented the intrusion of foreigners, so a detachment of soldiers accompanied the prospecting party. One can visualize the conditions when Janot was panning for gold: It was raining hard, the natives were hostile, and he had been away from home for nearly half a year. When he found some color in his pan (a few specks of yellow gold), he quickly put the concentrate, which included a bright shiny crystal, in a bag that eventually ended up in Brussels with all the other samples. P. Lancsweert, who inspected Janot's samples, recognized the crystal as diamond, and Shaler's accurate field notes helped them locate the probable discovery site (Buttgenbach, 1910; "How diamonds were discovered . . . ," 1925). The find was confirmed by Janot in 1911, when ruffled tribal feelings had settled down. Mining started in 1913, and the Tshikapa deposits became a steady producer of good-quality small stones (Bardet, 1974). They are still active.

At Tshikapa, diamonds are found in unconsolidated sands and gravels in and along the Kasai River and its tributaries—Tshikapa, Longatshimo, Tsiumbe, and Lubembe—which flow north from the Lunda region of Angola into the Kasai region of Zaire (Ball and Shaler, 1914). Early mining was carried out in small, scattered, and isolated workings with one or two Belgian supervisors and about 50 local workers. European-organized mining ended abruptly in 1961, after independence was attained, and has never been resumed. Virtually all mining is now done by locals, who produce several hundred thousand carats a year from this area.

After 1967, the national government tried to control the diamond industry in Western Kasai by allowing expatriate companies to set up buying offices. Nevertheless, even today production and trade still are not controlled by the central government. The number of carats purchased at the official buying offices rose from a few thousand in 1968 to close to 600,000 annually in the late 1980s and 1990s.

Mbuji-Mayi. The first diamonds at Bushimaie (now called Mbuji-Mayi) were found in December 1918 by George Young, a young Scottish geologist working for the Compagnie des Chemins de Fer du Bas-Congo au Katanga (Bécéka), a railway company that had been granted huge tracts of land for mineral exploration (Polinard, 1929). Young found more than 8,800 small diamonds in one location in a tributary of the Bushimaie River. The Société Minière du Bécéka was formed in 1919, and mining started at once with Forminière managing the operation for Bécéka.

Diamonds were found in gravelly soil and rock debris on low watersheds along the Bushimaie River and its tributaries, Kanshi, Mudiba, and Katsha. They came from several small kimberlites, discovered in 1946 (de Magnée, 1947). Their pipe stems are very narrow and are topped by small craters that contain a complex mixture of sandstone, kimberlite, clay, calcite, opal, and chalcedony rock and mineral fragments. Diamonds were found in eluvial (directly overlying the kimberlite) and colluvial (transported down slope), as well as alluvial deposits in the stream beds.

The diamonds were generally of poor quality (95% bort), but the grade was high (5 carats per tonne) and mining was low cost (Bardet, 1974). Consequently, large quantities were produced, reaching a peak of 18 million carats in 1961. This enormous production has made a significant impact on the world diamond market.

Bécéka was reorganized after independence into a new Belgian company, Sibeka (Société d'Investissements de Bécéka, later Société d'Entreprises et d'Investissements), which formed a subsidiary Miba (Société Minière de Bakwanga) to manage the Mbuji-Mayi mines. The Congolese (after 1970, the Zairian) government took a 50% equity in Miba; this was increased to 100% in 1971, and settled back to 80% in 1973. Miba produced only 4.6 million carats in 1992, whereas private licensed contractors and artisanal labor produced about 10 million from the same area, and illicit production for all of Zaire is estimated at another 10 million. After 75 years of large-scale surface mining, however, the easily accessible eluvial and colluvial deposits are becoming depleted, and operations are gradually moving to the alluvial deposits, which are being mined by large dredges. Yet the international financing needed to refurbish the Miba plant and dredges has not been forthcoming because of Zaire's unstable political climate.

From 1961 to 1967, almost all production left Zaire illegally through various African countries, notably the Central African Republic and Congo (Congo-Brazzaville). Diamond exports from Congo reached 6 million carats in 1967, but almost all of the stones exported actually came from the Tshikapa and Mbuji-Mayi areas, because there are no diamond mines in Congo. Accordingly, Congo is not listed as a producer of diamonds in figure 2; diamonds exported from this country are assigned to Zaire's production.

ANGOLA

An important African diamond producer, Angola exports up to 2 million carats of good-quality diamonds annually, primarily from alluvial deposits. Like Zaire, though, an unstable political situation has hindered both organized mining operations and prospecting. If unrest subsides, and order is restored, Angola will undoubtedly be an even greater player on the international market.

Alluvial Fields. The discovery of diamonds in the Tshikapa area of what is now Zaire encouraged the Guggenheim-Ryan group to extend prospecting farther upstream into the Lunda area of Angola. In July 1912, Donald Steel found the first diamonds in tributaries of the Luembe River (Legrand, 1984). The Companhia de Pesquisa Mineiras em Angola (Pema) was founded in Lisbon in 1913 to mine the diamonds (Castro, 1929). Production, which started in 1916, rose gradually from 100,000 carats in 1921 to nearly 800,000 carats in 1940.

In 1917, Pema was reorganized into the new Companhia de Diamantes de Angola (Diamang), and four years later Diamang acquired prospecting rights to virtually all of Angola (except the coastal strip) until 1971. Barnato Brothers and Anglo American purchased large share holdings in Diamang in 1923, and secured a contract that all diamonds produced would be sold to the Diamond Syndicate ("The Angolan diamond deal," 1923). To date, nearly all Angolan diamonds come from alluvial deposits in the Andrada and Lucapa areas of northeastern Lunda Norte and the Cuango River (figure 24). Diamond production reached a peak of 2.4 million carats in 1973.

In 1971, Diamang was restricted to about 50,000 km^2 in northeastern Lunda Province, and the Consorcio Mineiro de Diamantes (Condiama) was formed to take over the rights to all other areas. This consortium included the Angolan provincial government, De Beers, and Diamang. The newly independent Angolan government took over Diamang in 1976, and the following year made it a subsidiary of Empresa Nacional de Diamantes de Angola (Endiama); Diamang was finally dissolved in 1986. The complex history of the Angolan diamond industry up to the middle of 1992 is summarized in "The Angolan diamond experience" (1992), with an update to early 1995 provided in Gordon (1995). This includes the roles played by Endiama, Mining and Technical Services (MATS, an affiliate of De Beers that operated from 1979 to 1985), Sociedade Portuguesa de Empreendimentos (SPE), Rhodesian Selection Trust (RST), De Beers, and the Unita forces (whose invasion of the Cuango diamond fields in February 1985 led to the withdrawal of most foreign technicians).

With the onset of civil war following independence in 1975, official production dropped to a low of 270,000 carats in 1986. Although official annual production rose to about one million carats recently, Angola has a large illicit production (estimated at an additional one million carats in 1992) that is largely caused by the recurrent demobilization of soldiers. Once released, the soldiers would rather dig for diamonds than return to their farms. Illicit production decreases when military operations take place or heavy rains impede digging.

A law passed in October 1994 gave Endiama the exclusive right to all diamond deposits in Angola and empowered it to enter into joint ventures with foreign companies (with government approval). Licensed artisanal digging (manual diamond mining by local residents) is allowed in places where large-scale mining would not be lucrative.

Present alluvial operations are carried out in the Lucapa area by ITL Mining (a subsidiary of RST) on behalf of the Sociedade Mineira de Lucapa, a joint venture of Endiama and SPE. Alluvial operations in the Cuango Valley, which stopped when Unita forces reinvaded the diamond workings in November 1992, are starting up again. It is estimated that about 80% of Angolan diamonds produced in 1980–1992 came from this area (Gordon, 1995).

Kimberlites. There is only very limited production from eluvial and colluvial gravels overlying pipes such as the one at Camafuca-Camazomba, which was found in 1952 in the Chicapa River near Calonda (Real, 1958). This sinuous 3 km–long body, up to 550 m wide, covers an area of 75 ha (185 acres). Many other diamondiferous kimberlites were discovered in the Lunda Norte district and elsewhere in Angola in the 1970s (Jourdan, 1990, gives a total of 600). Prospecting activities by Diamang and Endiama indicated that at least five pipes in Lunda Norte may be economic: Camutue, Caixepa, Camatchia, Camagico, and Catoca. However, Angola's internal strife has hindered evaluation and development of pipes throughout the country. The Russia-Sakha Diamond Corporation (Almazy Rossii-Sakha), in a joint venture with Endiama and Brazil-based Odebrecht, was reportedly planning to develop the 66 ha Catoca pipe for open-pit mining. Development was delayed, though, as government forces recaptured the Catoca area only in July 1994 (Gordon, 1995).

De Beers is currently negotiating rights to prospect off-shore for submarine deposits and at several areas on-shore (Gordon, 1995).

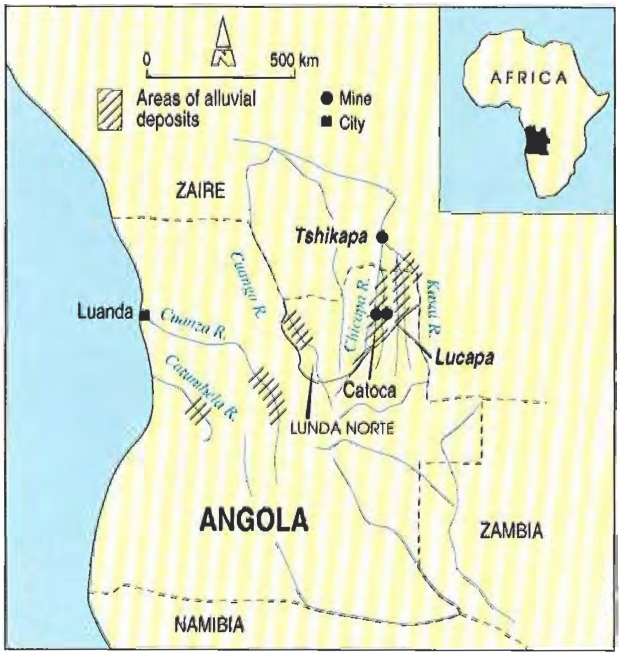


Figure 24. Most of the diamonds found to date in Angola come from alluvial deposits in the Lucapa and Cuango areas, in Lunda Norte Province.

CENTRAL AFRICAN REPUBLIC (C.A.R.)

The Central African Republic has been a small but steady producer of diamonds since the mid-1930s. All diamonds produced there to date came from alluvial deposits. The first diamonds were found in 1914 near Bria in the south central part of the country (Middleton, 1932). The major diamond-producing regions are Carnot-Berbérati in C.A.R.'s wet southwest and Mouka Ouadda in its dry northeast. Diamond production started in 1931. Mining was carried out by small French companies until independence was attained in 1961, after which syndicates of locals assumed control.

Since the early 1980s, foreign companies have again been allowed to participate in mining ventures. Osborne and Chappell Company attempted to dredge the Mambéré River (the main trunk river in the Carnot-Berbérati region) during 1989–1990, but the project was terminated because the results could not support a large mechanized mining operation.

Prospecting programs to evaluate the allegedly extensive colluvial deposits in the Bamingui-Bangoran area of the northeastern Mouka Ouadda region have been proposed since 1984. Canada-based United Reef recently raised venture capital to evaluate this project (Roux, 1994), and they started small-scale mining in June 1995.

Official plus unofficial production in C.A.R. is estimated at 500,000 carats annually for the last 33 years (based on *Mining Annual Review* reports for

Figure 25. The 128 ct fancy yellow Tiffany diamond was cut from one of the fabulous diamonds found in southern Africa, a 287 ct piece of rough reportedly recovered from a claim on the Kimberley mine in 1878. Photo by Josh Haskin; courtesy of Tiffany & Co.

1961–1994). Despite careful prospecting, no kimberlites or other primary host rocks have been found in this region, and all of C.A.R.'s diamonds are recovered from alluvial sources.

CONCLUSION TO PART I

The history of diamond and kimberlite discoveries in Africa spans nearly 130 years, from children playing with bright pebbles on De Kalk farm to high-technology exploration and excavation of tons of desert sand at Orapa and Jwaneng. During this period, all but two of the largest economic kimberlite pipes ever discovered were found (the other two are in Siberia). And several magnificent gem diamonds (see e.g., figure 25) were recovered. As a result, from 1872 to 1959, Africa produced 98% of the world's diamonds by weight, and 96% by value. Although, as will be discussed in Part II, these percentages have dropped dramatically in recent years, Africa is still the single most important diamond producer among the seven continents.

Historically, most of the diamonds have been produced by alluvial diggings—along rivers and streams in South Africa, Angola, and Zaire, in particular—and by large kimberlite pipes, such as those clustered in the Kimberley area and the prolific pipes in Botswana. However, diamonds from coastal deposits, such as those off the Atlantic Coasts of Namibia and Namaqualand, promise to be the industry's greatest future resource.

Part II will continue the story, focusing on the diamond-producing nations of eastern and western Africa. This part will also look at Africa's role in the development of theories on the geology and origin of diamond, as well as methods of diamond prospecting and mining. Special attention will be paid to the history of diamond production in Africa and key developments from the 1870s to the present.

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A CHART FOR THE SEPARATION OF NATURAL AND SYNTHETIC DIAMONDS

By James E. Shigley, Emmanuel Fritsch, Ilene Reinitz, and Thomas M. Moses

A chart is provided that describes those gemological properties that are key to the separation of gem-quality yellow, blue, and near-colorless (to colorless) natural diamonds from synthetic diamonds. This format was designed to give jewelers and gemologists a ready reference to identify synthetic diamonds as they enter the jewelry trade. Magnification and luminescence are the most important testing techniques currently available to jewelers and gemologists. The most distinctive features of synthetic diamonds include color zoning, graining, metallic inclusions (often making the stone magnetic), and uneven ultraviolet fluorescence.

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Now that small numbers of gem-quality synthetic diamonds have begun to appear in the jewelry industry, it has become critical that the professional jeweler/gemologist have the skills not only to quality grade a diamond, but also to identify that it is a natural, untreated stone. This article accompanies a chart that describes the distinctive gemological properties of natural as compared to synthetic gem diamonds (figure 1). In particular, the chart was designed to bring together in summary form those characteristics of gem-quality synthetic diamonds that will enable jewelers and gemologists to readily distinguish them from natural diamonds. This article describes the information contained in the chart, how it is organized, how it can be used in a standard gem identification procedure, and how the diagnostic gemological features can be resolved or recognized using standard gem-testing equipment. Some additional data, obtained through advanced techniques such as energy-dispersive X-ray fluorescence chemical analysis, infrared spectroscopy, and cathodoluminescence, are also cited because they provide useful information that the well-equipped gem-testing laboratory can use to support a conclusion. *With this chart, jewelers and gemologists alike have the means to identify the variety of gem-quality synthetic diamonds available at this time (see Box A).*

BACKGROUND

Over the past several years, various gemological researchers have published information on gem-quality synthetic diamonds and their practical gemological identification. Important articles include those by Crowningshield (1971), Koivula and Fryer (1984), Shigley et al. (1986, 1987, 1993a, 1995), Ponahlo (1992), Rooney et al. (1993), Moses et al. (1993a), Scarratt et al. (1994), Kanda and Lawson (1995), and Sunagawa

Figure 1. Shown here are some of the synthetic diamonds examined by GIA researchers to date (clockwise from top photo): (1) three faceted (0.39 ct yellow, 0.31 ct grayish blue, and 0.30 ct near-colorless) synthetic diamonds and one crystal (0.73 ct near-colorless) grown experimentally by General Electric; (2) three Sumitomo yellow crystals (top, 0.63–1.07 ct) and four yellow synthetic faceted stones (0.16–0.24 ct); (3) a 0.14 ct synthetic diamond with a dark red color caused by treatment; (4) De Beers experimental yellow synthetic diamonds—0.30 ct (left), 0.27 ct (right), and a 1.03 ct crystal (top); (5) a 0.42 ct near-colorless crystal produced in Russia; (6) two yellow Russian as-grown crystals (left, 0.78 ct; right, 0.88 ct), plus three as-grown (0.18–0.51 ct) and two treated (0.14–0.21 ct) faceted synthetic diamonds. Photos are by, again clockwise from top, Tino Hammid (first two), Shane F. McClure, Tino Hammid, Shane F. McClure, and Robert Weldon.

BOX A: A PRACTICAL GUIDE FOR SEPARATING NATURAL FROM SYNTHETIC DIAMONDS

Synthetic diamonds have a number of gemological properties by which they can be identified reliably. However, this requires that jewelers look at diamonds more carefully, and document more properties than they traditionally have documented. The following is a step-by-step procedure, to be used in conjunction with the information and illustrations on the chart, by which synthetic diamonds can be identified by any trained gemologist using standard gemological equipment.

MAGNIFICATION

The first step in grading, appraising, or purchasing a diamond is to examine the stone with magnification, preferably with a gemological microscope. This procedure, in which the observer determines such important information as the clarity and other grading parameters, is also critical to determining whether the diamond is natural or synthetic.

Careful observation of the inclusions present often reveals the identification of the diamond conclusively. For example, an included crystal of a transparent guest mineral such as garnet, enstatite, or diopside—or of another diamond—identifies the diamond as natural. Conversely, if you see a dark, opaque inclusion, you would want to look at it very carefully using such lighting methods as fiber-optic illumination to determine if its luster is reflective and metallic (figure A-1). If so, it might be a piece of metallic flux, in which case testing for magnetism (see below) would be sufficient to prove that it is a synthetic.

In situations where the diamond is of higher clarity and no diagnostic inclusions are present, close examination of growth features may aid in identification. "Hourglass" graining, which is usually visible through the pavilion, is related to the octahedral and cubic internal growth sectors of synthetic diamonds. Consequently, the presence of hourglass graining is proof that the diamond is synthetic. Any graining (colorless, colored, whitish, green, or even surface graining) following the octahedral planes throughout the stone would indicate that the diamond is natural. Likewise, phantom graining along the octahedral directions would also serve to identify a diamond as natural.

In a colored diamond, any color zoning observed can be useful for making the identification; examination with diffused transmitted light is very helpful in this regard. Natural diamonds may show planar bands of color or a roiled effect, but only synthetic diamonds would show patterns related to the internal growth sectors.

ULTRAVIOLET FLUORESCENCE

If no diagnostic features are seen with magnification, or to confirm a preliminary identification made on the basis of internal features, you would look next at the reaction to long- and short-wave ultraviolet (UV) radiation. In most instances, there will be some distinguishing fluorescence features present. In the past, the fluorescence reactions of diamonds were not perceived as key identifying features by the jeweler or gemologist, who was solely concerned with grading concepts such as the strength and color of the reaction to long-wave UV radiation. For grading purposes, the diamond is placed table down under a long-wave UV light source in partial darkness. For identification purposes, it is preferable to view the stone from all directions, under both wavelengths of UV light, in total darkness. In the latter case, the pattern (or zoning) of the fluorescence is often more important than the fluorescence color.

A natural diamond typically fluoresces blue to long-wave UV (LWUV) radiation, with a weaker and usually yellow reaction to short-wave UV (SWUV). This fluorescence is usually evenly distributed, but it may be planar. Conversely, synthetic diamonds typically fluoresce yellow to yellowish green to both LWUV and SWUV, with the reaction often noticeably stronger to short-wave than long-wave. In addition, the internal growth sectors of a synthetic diamond generally produce a cross-shaped, octagonal (or similar geometric) pattern of fluorescence to either or both wavelengths.

In some cases, fluorescence may be stronger to LWUV than to SWUV, or the reaction to both wavelengths may be similar in strength, unlike the noticeable difference in intensity usually present in natural diamonds. Low magnification can be useful to observe any zoning of the fluorescence reaction. (An Optivisor is well-suited for this purpose; if a microscope is adapted for this use, precautions should be taken to shield the operator's eyes from the short-wave UV radiation.)

Ultraviolet fluorescence is a test commonly used by jewelers and gemologists, and simple observations such as these may identify the diamond conclusively. In addition, an entire parcel of stones can be tested at one time.

SPECTROSCOPY

To date, most of the gem-quality synthetic diamonds encountered in the trade have been yellow to brownish yellow in body color; they have been identified as synthetic during the testing procedure used to determine their "origin of color." Observation of the spectrum—with a prism or diffraction-grating (hand-held or desk-model) spectroscope—is a routine test for colored diamonds. The spectra of most natural diamonds, whether of natural or treated color, differ from those seen in synthetic diamonds. The most common spectral features seen in natural diamonds are the "Cape" lines at 415 nm and at 452, 465, and 478 nm. On the basis of the samples we have examined to date, we believe that the presence of a 415 nm line in a colorless to light yellow diamond can be considered proof that the stone is natural.

Treated-color natural diamonds may show additional absorptions at 496, 503, 595, or 637 nm. Such spectral features suggest that the diamond is natural (even if the color is treated). Absence of the 415 nm line would not prove that the diamond is synthetic, but it would make it necessary to test the stone further.

Some synthetic diamonds show a number of absorption lines between 470 and 700 nm (see chart), which are due to the nickel used in the flux. Observation of several of these lines would indicate a synthetic. However, most colored synthetic diamonds are predominantly type Ib, so no sharp absorption features are expected in the visible spectrum. Rarely, natural diamonds are type Ib or type IIa, and these are not expected to show spectral lines.

MAGNETISM

The metal fluxes used to help grow synthetic diamonds often leave metallic inclusions—from submicroscopic particles to eye-visible pieces—in the synthetic stone. Such inclusions are magnetic and may be attracted by a strong magnet. To detect this magnetism, the diamond can be suspended from a string and sheltered against air currents, while the magnet is placed close to the stone (but not touching it). Moving the magnet from side to side should induce a parallel motion in a synthetic diamond, but will cause no movement in a natural stone.

As mentioned above, observation of a dark inclusion with a metallic luster would lead you to perform this test, although finely dispersed flux that is not resolvable under magnification may also react to a magnet. Thus, a clear response of the diamond to the magnet *proves* that it is synthetic, but lack of a magnetic response only *suggests* that it is natural. In rare instances, a natural diamond may contain inclusions that cause the stone to be faintly attracted to a strong magnet, but such a diamond will undoubtedly have other properties that prove it to be natural.

STRAIN

Anomalous double refraction (ADR), commonly called "strain," is a characteristic of diamonds that normally goes unnoticed by the jeweler or gemologist, although it is well known to diamond manufacturers. It can be observed by holding the diamond from table to culet under a polariscope or between crossed polarizing filters attached to a gemological microscope. Although this is not a "stand-alone" test, it is particularly useful when the stone is free of inclusions, is of high color, or shows no "Cape" series in the spectroscope. Natural diamonds generally show banded, cross-hatched, or mottled strain patterns and bright interference colors, whereas the strain present in synthetic diamonds shows a cross-like pattern in subdued colors, mainly black and gray.

Figure A-1. A group of metallic inclusions is seen here under the table facet of a brownish yellow synthetic diamond. Although the square shape of the inclusions is somewhat unusual, their opaque appearance in transmitted light is very characteristic. Photomicrograph by John I. Koivula; magnified 25×.

SUMMARY

Whether the diamond is ultimately to be examined for grading or for its origin of color (procedures that differ considerably), you can determine the stone's natural or synthetic origin by using one or more of these basic gemological tests:

1. Examine the stone with magnification, looking for inclusions, color zoning, and graining.
2. Observe the UV fluorescence, especially with the stone in the face-up position, looking for both a fluorescence pattern and the relative strength of fluorescence to LWUV and SWUV.
3. Look at the spectrum with a hand-held or desk-model spectroscope.
4. Check whether a suspected synthetic reacts to a strong magnet.
5. If necessary, observe the strain patterns/colors between crossed polarizers.

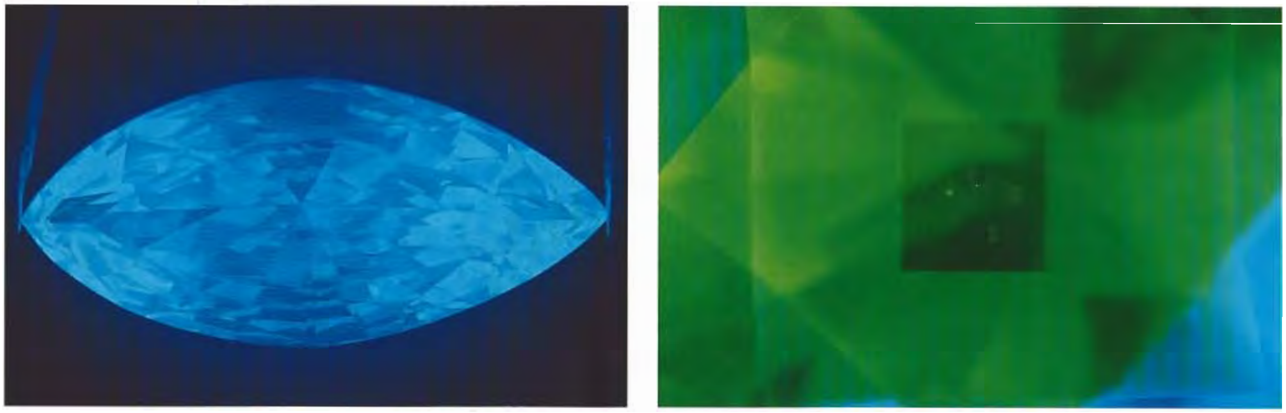
(1995). Other articles, taken mainly from the gemological literature, are provided in the "Additional Reading" addendum to the "References" list. The purpose of all these articles has been to inform the jewelry trade (and, indirectly, the public at large) about synthetic gem diamonds from various manufacturers (in particular, experimental samples from General Electric and De Beers, and commercial material from Sumitomo and various Russian laboratories [again, see figure 1]). The articles have also demonstrated how to identify those gemological characteristics that trained jewelers and gemologists can use to separate synthetic diamonds from their natural counterparts.

We believe that, to date, synthetic diamonds of a size and quality suitable for faceting have been grown only in limited numbers and have had little, if any, adverse impact on the jewelry industry. However, as the costs of production go down (with improvements in the technology of diamond synthesis), it is possible that such synthetics will be less rare in the future. The only synthetic diamonds encountered in the trade by the GIA Gem Trade Laboratory (GIA GTL) have been yellow (10 samples seen since 1987 with nine of these seen since 1993: see, e.g., Moses et al., 1993b; Kammerling et al., 1993, 1995b) or red (three samples seen, all with the color due to laboratory treatment; the first two are described in Moses et al., 1993a). A faceted 1.23 ct brown-yellow synthetic diamond was examined by staff members of the Hoge Raad voor Diamant (HRD) certificates laboratory in Antwerp (van Royen, 1994, p. 44). A 2.32 ct brown-yellow brilliant-cut pear-shaped synthetic diamond was reported by the Gemmological Association of Great Britain Gem Testing Laboratory in London (Emms, 1994). Synthetic yellow diamonds from Russia have also been examined by gemologists in Germany (Henn and Bank, 1993), Thailand (Scarratt et al., 1994), and Italy (Sosso, 1995). The largest faceted synthetic diamond known to date is a 5.47 ct brownish yellow stone (cut as a round brilliant) that was identified in early 1995 by staff members of GIA GTL. Despite the limited numbers of synthetic diamonds seen, the fear that they will enter the marketplace and will not be readily identifiable continues to haunt the trade (see, e.g., Costan, 1993; Nassau, 1993; "Chatham to sell 'created' diamonds," 1993; Helmer, 1994; Howard, 1995).

Most synthetic diamonds are brownish yellow to yellow, but blue and near-colorless crystals have also been grown in limited numbers, thus far primarily for experimental purposes. In all colors, samples suitable in size and quality for jewelry use have been faceted.

According to the research work published to date, those synthetic diamonds available thus far have several distinctive gemological properties that allow for their identification using readily available gem-testing techniques. For both as-grown and laboratory-treated colored synthetic diamonds (which tend to have saturated hues), we have found that the most diagnostic gemological properties are certain patterns of uneven color; uneven yellow to yellowish

Figure 2. Natural diamonds, like the 0.69 ct near-colorless stone shown here on the left, typically fluoresce a relatively even blue to long-wave UV radiation. In contrast, synthetic diamonds, like this 0.13 ct yellow synthetic on the right, typically fluoresce yellowish green to short-wave UV radiation, with an uneven (cross-like) pattern (the blue color at the lower right is merely a reflection of the UV lamp). Photomicrographs by John I. Koivula; magnified 5× (left) and 15× (right).



green ultraviolet (UV) fluorescence (figure 2), which is often stronger to short-wave (SWUV) than long-wave (LWUV) ultraviolet radiation; and certain graining patterns, as well as the presence of metallic flux inclusions. For near-colorless to colorless synthetic diamonds, the diagnostic properties are certain patterns of uneven UV fluorescence (so far, *always* stronger to SWUV), persistent phosphorescence, and metallic flux inclusions.

The zonation of color, UV fluorescence, and graining that is often so prominent in synthetic diamonds results from their internal structure, which contains octahedral, cubic, and sometimes additional growth sectors. Chemical impurities trapped from the laboratory growth environment are concentrated either along the boundaries between internal growth sectors, or in one sector and not in adjacent ones, in the synthetic diamond crystal (see Kanda and Lawson, 1995). The distinctive features of as-grown synthetic diamonds result from those conditions of diamond formation in the laboratory that differ from those in the earth (mostly in that diamonds are grown in a silicate solution in nature and a metallic solution in a laboratory; see Sunagawa, 1984, 1995).

The color of brownish yellow synthetic diamonds can be altered to either pink to red, or yellow to greenish yellow, by treatment processes such as irradiation followed by heating (Moses et al., 1993a), or heating at high pressure (Shigley et al., 1993a), respectively. These treatment processes will also alter gemological features such as UV fluorescence and absorption bands seen with a hand spectroscope (see italicized text on chart). Nevertheless, a treated synthetic diamond is no more difficult to detect than its untreated synthetic counterpart.

Although there are many similarities in gemological properties among synthetic diamonds from various manufacturers, and among those treated by different processes, there are also some differences. It is because of this that we decided to bring together in chart form those features that we currently know to be useful in the identification of synthetic diamonds.

CONTENTS OF THE CHART

The chart presents information on synthetic (both as-grown and laboratory-treated) diamonds and their natural counterparts in a vertical format organized by three general color groups: yellow, colorless to near-colorless, and blue. For each general color group, we have summarized only the most useful gemological properties. For the most part, we chose to restrict information to properties of faceted natural or synthetic diamonds that could be documented readily by gemologists, although some other features such as crystal size and shape are included. Sunagawa (1995) provides a comprehensive discussion of the differences in morphology, surface features, and internal characteristics of rough natural and synthetic diamond crystals.


Figure 3. The Luminoscope, manufactured by Premier American Technologies Corp., consists of two parts: On the left is the vacuum chamber and electron "gun," and on the right is the power supply and control unit. Diamonds will emit visible cathodoluminescence when they are bombarded by the electron beam in the vacuum chamber. Photo courtesy of Premier American Technologies Corp., Bellefonte, Pennsylvania.

Some information derived from three other identification techniques—cathodoluminescence, energy-dispersive X-ray fluorescence (EDXRF) chemical analysis, and infrared spectroscopy—is also included on the chart. We believe that cathodoluminescence (luminescence generated by exposure of a material to a beam of electrons in an evacuated chamber), in particular, will soon become a more standard technique for testing diamonds in gemological laboratories (see Ponahlo, 1992, and photographs of cathodoluminescence in Shigley et al., 1987, 1993a). A relatively simple unit (known as a Luminoscope), which is capable of generating cathodoluminescence in diamonds and other gemstones, can be purchased for about US$20,000 (figure 3). It consists of a sample chamber (from which the air can be evacuated, and which can

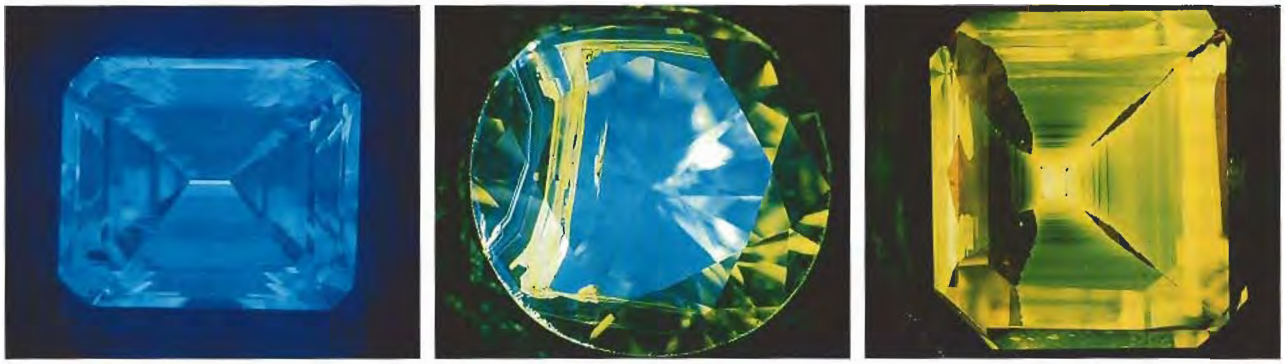


Figure 4. The natural diamond on the far left shows the relatively even blue cathodoluminescence typical of natural diamonds. However, some natural diamonds (center) exhibit a cathodoluminescence pattern that reflects their complex growth history. Nevertheless, these patterns are distinctly different from the green-to-yellow, cross-shaped cathodoluminescence pattern typically seen in synthetic diamonds (here, a crystal grown experimentally by De Beers). Photo on the left is by Maha DeMaggio (magnified 5×); center and right photos are by Michael Crowder, De Beers Research Centre, Maidenhead, UK (magnified 6× and 2×, respectively).

be mounted on a microscope stage, if desired) with a viewing port, a "gun" that emits an electron beam, and the associated power supply. Our observations indicate that no diamond, natural or synthetic, is inert to cathodoluminescence (which is not the case with UV fluorescence). In addition, although the colors of luminescence generated by UV fluorescence and cathodoluminescence may differ, the characteristic *pattern* of internal growth sectors in a synthetic diamond can often be seen more easily using cathodoluminescence (figure 4). In those cases where the UV fluorescence is weak or indistinct, in particular, we have found that the more intense cathodoluminescence will reveal the presence of different internal growth sectors in synthetic diamonds (see Shigley et al., 1987, 1993a and b; Ponalho, 1992).

In this chart, we also cite some EDXRF chemical analysis results. This method is routinely used at gem-testing laboratories to distinguish natural, treated, and synthetic gem materials. Our EDXRF data indicate that synthetic diamonds typically contain traces of the flux metals (such as iron or nickel) from which they are grown (see, e.g., the EDXRF spectrum in Moses et al., 1993a, p. 185, and the data in Shigley et al., 1993a, p. 234, which indicate the presence of Fe and Ni in both as-grown and treated Russian synthetic diamonds). They may also contain elements such as aluminum or titanium that were added to the experimental system to remove nitrogen from the growing diamond crystal. Natural diamonds generally do not have trace impurities that can be detected by EDXRF (which cannot detect any of the low-atomic-number elements—such as carbon, nitrogen, or boron—typical of the major- and trace-element chemistry of natural diamond). On rare occasions, natural diamonds with mineral inclusions (such as garnet) may exhibit evidence of trace amounts of Si, Al, Fe, Mg, or Ti. Diamonds polished on an iron scaife may exhibit features consistent with Fe contamination.

Finally, we have included information that refers to diamond type (e.g., Ia, Ib, IIa, IIb), a traditional scheme used to classify all diamonds on the basis of their nitrogen and boron contents by means of infrared spectroscopy (for a good, concise discussion of diamond type, see Fritsch and Scarratt, 1992, pp. 38–39). This classification of diamond is important because the type categories can be related to the gemological properties that diamonds exhibit. As-grown synthetic yellow diamonds are type Ib, a type that is very rare in nature; those that are treated at high pressure or that are irradiated and heat treated can be predominantly type IaA. Blue synthetic diamonds are type IIb (as are most natural blues), whereas the near-colorless to colorless synthetics studied to date are usually type IIa. The type categories of corresponding colors of natural diamonds are also listed on the chart. It is important to note, however, that natural diamonds referred to as type Ib, unlike synthetics, are rarely "pure" and usually contain some type Ia nitrogen.

Details of how these gemological properties were documented in both synthetic and natural diamonds are briefly presented in the "Key to Information" section at the bottom of the chart.

Note that the chart does not present information on natural diamonds that might have a synthetic diamond coating placed on them to change their color or possibly their weight. In the course of our research, we arranged to have three natural type Ia colorless diamonds coated with a layer of blue, type IIb synthetic diamond (Fritsch, 1991; Fritsch and Phelps, 1993). These three stones could be readily recognized by the uneven deposition of the synthetic diamond coating, resulting in irregularities in blue coloration (especially along facet junctions), as well as by distinctive features in their visible and infrared absorption spectra. To date, we have neither encountered nor heard of any situations where a synthetic diamond coating has been applied to a natural diamond primarily to change its weight or color.

HOW THE INFORMATION IS ORGANIZED

Within each column, we present in summary form only what we believe to be *the most commonly seen* gemological properties. We should emphasize that not all of these diagnostic features are likely to be found in each synthetic diamond. However, all synthetic diamonds we have examined to date display one or more of these features. As stated earlier, the most useful diagnostic properties include such features as color zoning, graining, metallic inclusions (microscopic and submicroscopic), usually causing the synthetic diamond to be attracted to a strong magnet (e.g., the neodymium-iron-boron magnet "wand" developed by Alan Hodgkinson, described in Kammerling et al., 1995a), and uneven luminescence to both UV and electron radiation. Synthetic diamonds of a particular color have many similar gemological properties, although—as noted above—some differences may exist between samples from various manufacturers. Among natural diamonds, however, the variation in gemological properties can be much greater because of differences in both growth history and impurity contents in crystals from one locality to the next. Thus, there is a greater possibility for exceptions to the information on natural diamonds presented in the chart than to that given for synthetic diamonds.

The chart also includes a number of photographs and photomicrographs. These pictures were selected to illustrate visual features of synthetic and natural diamonds that have the greatest diagnostic value for identification purposes. The photographs are referenced by number (FIG = figure) in the relevant portions of the chart.

HOW THIS INFORMATION WAS ACQUIRED

Most of the information presented in this chart is based on data collected by GIA researchers over the past eight years on approximately 120 synthetic diamonds. Information on natural diamonds comes from our documentation of the gemological properties of several thousand diamonds. Information on natural and synthetic diamonds reported by other researchers was compared with our data to confirm the information shown on the chart.

CONCLUSION

The accompanying chart summarizes the key characteristics of synthetic and natural diamonds, emphasizing the information that can be obtained by standard gem-testing methods, such as magnification, ultraviolet fluorescence, and optical absorption spectra. *Synthetic diamonds currently being marketed can be identified positively and reliably on the basis of the information presented in this chart.*

The chart also provides information derived from more advanced testing methods, such as cathodoluminescence, EDXRF chemical analysis, and infrared spectroscopy, where this information can provide confirmation of natural or synthetic origin.

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DIAMOND

Fancy Black, with Iron

One technique that we sometimes apply to diamonds suspected of being synthetic is energy-dispersive X-ray fluorescence spectroscopy (EDXRF). Because iron (Fe) and nickel (Ni) are used in the catalyst for synthetic diamond formation, these elements are found in the metallic flux inclusions in many synthetic diamonds and are detectable by EDXRF even if no flux inclusions can be identified. However, the mere presence of Fe and/or Ni is not proof of synthetic origin.

Last summer, the West Coast laboratory received a 9.61 ct semi-translucent, marquise-cut black diamond for origin-of-color determination. Natural-color black diamonds typically owe their color to numerous black inclusions. Magnification revealed that this heavily included stone was no exception: The black inclusions were arranged in bands, with brown and near-colorless bands also present. In addition, large fractures in the stone showed brown staining. Although an EDXRF spectrum was not needed to determine cause of color, we ran one to see if it would show anything about the inclusions. It revealed that iron was present in the stone, probably as the brown iron-oxide stains in the large fractures. Another possible source is residue from the polishing wheel. Such build-up is particularly common in black diamonds, because they contain so many fractures and cavities. The black inclusions that gave the stone its color were probably graphite, since no additional elements showed up on the EDXRF (which cannot detect carbon and other low-atomic-number elements).

Thus, the presence of iron in a diamond does not by itself prove that the stone is synthetic. However, this stone was not attracted to a powerful hand-held magnet, despite its detectable iron content; the iron-nickel flux found in synthetic diamonds is strongly magnetic. *MLJ*

Fracture-Filled with Unusual Material

Although we have known of fracture-filling as a diamond treatment since the mid-1980s, only recently has this treatment received widespread publicity. Consequently, some stones that were treated in the 1980s may have gone through several owners by now. Even if treatment had been disclosed originally, such disclosure might not have been passed down to subsequent owners. As another complicating factor, the body color of the stone can obscure the diagnostic flash colors in fracture-filled diamonds, making recognition of this diamond treatment more difficult in fancy-color stones (see, e.g., "A Visual Guide to the Identification of Filled Diamonds," by S. F. McClure and R. C. Kammerling, *Gems & Gemology*, Summer 1995, pp. 114–119; as well as the Summer 1991 [p. 109] and Fall 1995 [pp. 198–199] Lab Notes).

In September 1995, the West Coast laboratory received a 1.07 ct yellowish orange cut-cornered rectangular modified brilliant (figure 1) for an origin of color report. The apparent clarity of the stone was low (in the I_2–I_3 range); one large feather traversed the table, and others were present. We were surprised to find blue and orange flash colors associated with the larger feathers (figure 2). Even more surprising was that EDXRF spectroscopy, which we used to confirm the presence of the filling substance, showed that the filler contained thallium (Tl) in addition to the more typical Pb and Br that we have previously documented in filled diamonds. Some early fillers had been rumored to contain thallium, a heavy element that contributes to high refractive indices in glass, but is hazardous to work with because of its extreme toxicity. It is possible that this toxicity is why thallium has not been found in more recent filling materials studied by the GIA Gem Trade Laboratory (see R. C. Kammerling et al., "An Update on Filled Diamonds: Identification and Durability," Fall 1994, pp. 142–177, as well as the above-mentioned references). Therefore, we suspect that this stone may have been one of the earlier filled diamonds.

MLJ, SFM, and Dino DeGhionno

JADEITE JADE

Extremely Thin Carving

A Fall 1995 Lab Note (pp. 199–201) described two "carvings" that the West Coast lab determined were really assemblages. They consisted of

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Editor's note: The initials at the end of each item identify the contributing editor(s) who provided that item.

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Figure 1. The presence of thallium in the substance with which this 1.07 ct diamond was filled suggests that it was treated some time ago, possibly in the mid-1980s.

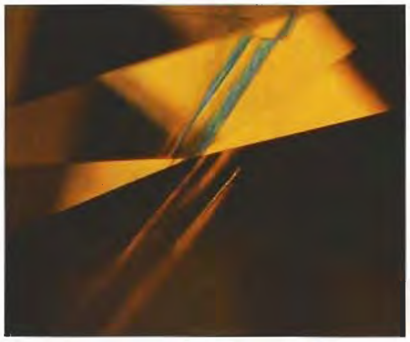


Figure 2. The yellowish orange body color of the diamond shown in figure 1 almost masked the orange darkfield flash color; even the blue brightfield color seems subdued. Magnified 25×.

thin, hollowed-out shells of natural-color green jadeite jade that were filled with a transparent, colorless plastic. In early fall 1995, we received for identification what initially appeared to be a related item: a translucent, mottled green-and-white piece of a carving (figure 3). Standard gem-testing methods revealed a 1.66 spot R.I., an aggregate polariscope reaction, and a 437 nm absorption line, which confirmed that it was jadeite jade. Fine absorption lines in the red portion of the spectrum proved that the green color was natural. The item was unusual not only for its extreme thinness, but also because it had been carved so that raised areas on one side complimented recessed areas on the opposite side. We speculated that this might have been done to maintain a uniform thickness—and resultant uniform depth of color—across the entire item. During the examination, we also saw a colorless foreign material on small scattered areas of the surface (which we noted in the report's conclusion; possibly this material was the glue used in the setting process).

At first we thought that the item might be the top layer of an assemblage, similar to the assemblages described in the previously mentioned Fall 1995 Lab Note (but minus the plastic filling). However, in a subsequent discussion with the client we learned that the carving, which had been mounted in a pendant, was damaged while being transported in a suitcase. Therefore, it is possible that the carving originally was just a thin shell of jadeite. Without the added durability provided by a plastic filler, the item would have been quite susceptible to breakage when pressure was applied to its surface.

RCK and SFM

A Testing Precaution

Submitted to the East Coast laboratory for examination, the ring-mounted cabochon in figure 4 was determined to be natural-color jadeite jade by standard gem-testing methods. However, testing for plastic impregnation by infrared spectroscopy—routinely done on all jadeite submitted to the laboratory—was inconclusive.

We therefore asked the client to have the stone removed from the setting for further testing. Once the stone was out of the setting, we saw that it was really a half bead, with the remnants of the drill hole clearly visible along its base. We also noted that the half bead had been cemented into the setting; the adhesive fluoresced weakly to long-wave UV radiation (figure 5). When the polymer cement was completely removed, further infrared spectroscopy testing gave no indication of polymer.

This instance should serve as a caution to gemologists: Examine jadeite pieces carefully for evidence of repairs, setting cements, and the like. Otherwise, an "innocent" piece of jade might be wrongfully identified as "B" (plastic-impregnated) jade.

GRC

Impregnated SYNTHETIC OPAL

The Summer 1995 Gem News column contains a preliminary report on plastic-impregnated synthetic opal being produced by the Kyocera Corporation of Kyoto, Japan (pp. 137–139). When samples were first obtained for examination—at the Tucson gem shows in February 1995—the material was reportedly only being test marketed in Korea and Japan.

Shortly after the Gem News entry appeared, the West Coast lab received for identification a 3.42 ct piece of partially polished, translucent, black rough with play-of-color.

Figure 3. This jadeite carving (26.55 × 18.00 mm) is extremely thin, only about 0.13 mm in some areas, as shown by the chip at the bottom left.

Figure 4. The material used to cement this natural-color jadeite "cabochon" (7.55 × 7.63 × 8.45 mm) to its setting produced ambiguous readings in the stone's infrared spectrum.

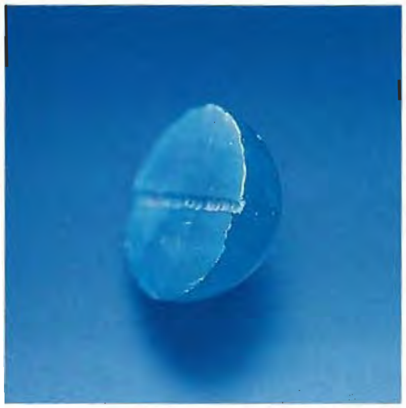


Figure 5. Once the stone in figure 4 was taken out of its setting, we realized that the "cabochon" was actually half a bead. Note the weak fluoresence of the adhesive to long-wave UV.

Because the piece closely resembled (in body color, diaphaneity, and play-of-color pattern) some of the treated synthetic opals we had recently examined, our suspicions were immediately aroused.

An R.I. reading taken from the side of the piece gave a value of 1.44. However, the top gave a reading of 1.50, unusually high for either natural or synthetic opal. We tentatively attributed this to surface "overflow" of the impregnating substance (see below). Specific gravity, determined hydrostatically, was 1.82, too low for untreated synthetic opal, but only slightly lower than the lowest values that we had obtained on the Kyocera treated synthetic opal.

The faint orange fluorescence to short-wave ultraviolet radiation, with no reaction to long-wave UV, was consistent with our observations on Kyocera test samples with a similar body color. Magnification revealed the "lizard-skin" pattern typical of synthetic opal and a pronounced columnar structure perpendicular to this pattern. With magnification, we also saw that the surface that gave the higher R.I. value had a thin, transparent, colorless coating.

Because of the unusually low S.G. and our recent experience with plastic-impregnated synthetic opals, we examined the specimen with Fourier Transform infrared (FTIR) spectroscopy. Opal is opaque to the infrared below 4000 cm^{-1}; however, this spectrum showed several absorptions between 6000 and 4000 cm^{-1}, which are not seen in natural opal (but were seen in the Kyocera material) and which we attribute to an impregnating polymer.

On the basis of all of these results, and following GIA Gem Trade Laboratory policy of disclosing any treatments detected, the specimen was identified as impregnated synthetic opal. *RCK and SFM*

SYNTHETIC QUARTZ, Green and Yellow Bicolor

Green quartz, sometimes known by the trade name "prasiolite," is a challenging material to identify. In the past, much of the green quartz on the market was heat-treated amethyst, the so-called "greened amethyst" (see, e.g., Summer 1983 Lab Notes, p. 116). Natural green quartz occurs in at least one area in California where amethyst was subjected to natural heating (volcanic activity; see T. Paradise, "The Natural Formation and Occurrence of Green Quartz," *Gems & Gemology*, Spring 1982, pp. 39–42). Citrine is also found at this locality. Recently, synthetic quartz from Russia has become available in many colors, including green; synthetic green quartz, misrepresented as natural material from Brazil, was discussed in a Winter 1992 Lab Note (p. 265).

In May 1995, the West Coast lab received for identification a bicolored—yellowish green and orangy yellow—emerald cut (figure 6). Most of the gemological properties were typical for quartz, but they were not useful in determining whether this stone was natural, treated, or synthetic. Among the properties that pointed to synthetic origin were: color zoning in planes perpendicular to the optic axis (not known to occur in natural quartz), lack of twinning (twinning was seen in three natural [control] "prasiolites" examined), and scattered "breadcrumb" inclusions (much more common in synthetic than in natural amethyst, which is what we would expect this stone to have originated as if it was natural quartz).

However, EDXRF, UV-visible, and infrared spectroscopy also demonstrated features unlike those typical for natural citrine or green quartz, including: significant potassium (seen with EDXRF); sharp peaks in the UV-visible spectra of both green and yellow regions at about 345, 398, 420, 458, and 487 nm (may be caused by Co^{3+}); and a "hump" in the infrared absorption spectrum at about 3000 cm^{-1}. This combination of features proved that this material was indeed synthetic quartz.

MLJ, SFM, RCK, and Emmanuel Fritsch

ROCK Resembling Jadeite

The opaque variegated green-and-white cabochon (15.50 × 7.00 mm) in figure 7 was cemented to a snuff-bottle stopper. According to the client who submitted it to the East Coast lab for identification, this material closely resembled that of the bottle to which it belonged.

Although a spot reading on the refractometer was within the jadeite range, there was a noticeable birefringence—in fact, a "carbonate blink" —from 1.50 to 1.65. However, no effervescence occurred when a minute drop of dilute HCl acid was placed in an inconspicuous spot on its surface. Effervescence would be expected if the cabochon were either of the carbonate minerals calcite or aragonite.

As our testing at this point was inconclusive, we performed X-ray diffraction analysis. This revealed that the cabochon was a rock consisting principally of dolomite, a little quartz, and other, unidentified, minerals. Dolomite is one of the few carbonate minerals that do not effervesce (unless powdered) to a weak HCl acid solution. To determine what the unidentified minerals were, petrographic testing would have been required. We informed the client of this in the report's conclusion.

GRC

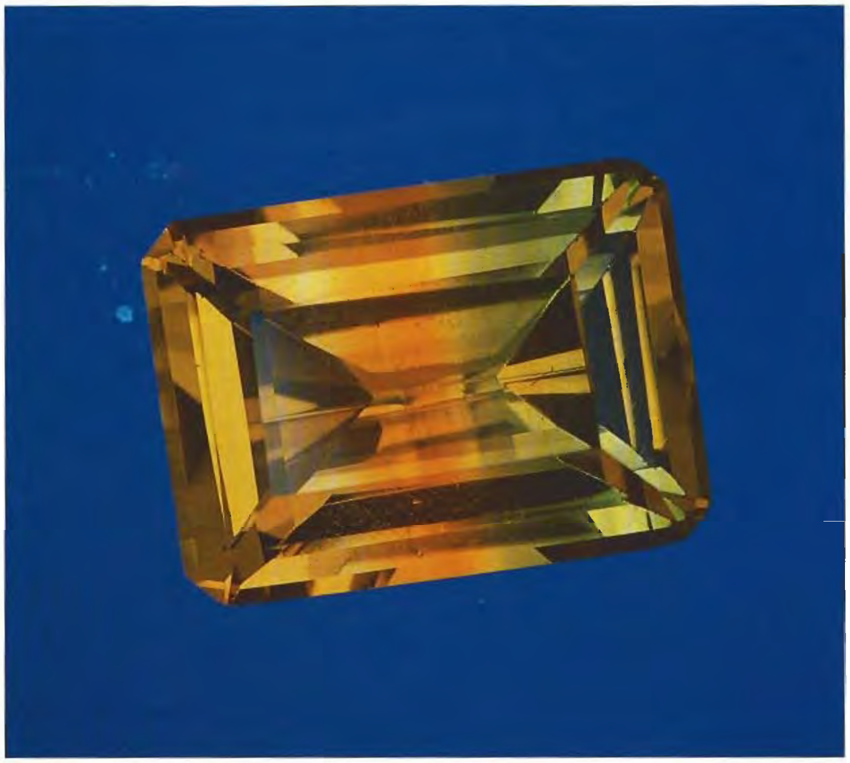


Figure 6. Testing revealed that this 8.47 ct green-and-yellow bicolor is a synthetic quartz.

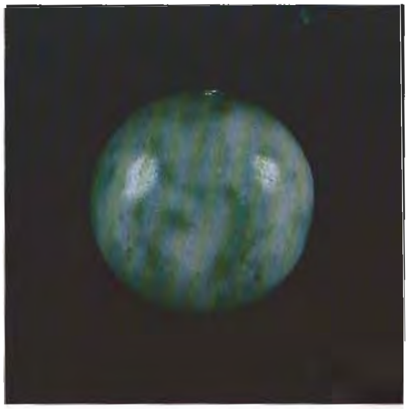
RUBY

With Atypically High R.I.'s

The article "Update on Diffusion-Treated Corundum: Red and Other Colors" (S. F. McClure et al., *Gems & Gemology*, Spring 1993, pp. 16–28) focused on treated stones in purplish pink, reddish purple to purplish red, and orangy red hues. One feature documented in many of these sample stones, in contrast to documented blue diffusion-treated sapphires, was the presence of unusually high refractive indices. The authors speculated that this was due to the high chromium content in the diffused surface layer, and they made reference to a report in the literature mentioning high R.I. readings from high-chromium-content rubies and orange sapphires from Malawi.

Recently, the West Coast lab was asked to identify a 1.19 ct red oval mixed cut. Standard gemological testing identified the stone as natural ruby, and internal features were indicative of heat treatment. We were surprised, however, by the unusually high refractometer readings: n_ε = 1.769, n_o = 1.778. EDXRF chemical analysis by GIA Research revealed an unusually high chromium content: 2.77 wt.% Cr_2O_3.

Figure 7. This cabochon, which formed the top of a snuff bottle stopper, consists of dolomite, some quartz, and other, unidentified, minerals.



In "Rubies from Mong Hsu" (*Gems & Gemology*, Spring 1995, pp. 2–26), authors Peretti et al. note that rubies from this relatively new Myanmar locality have unusually high chromium contents (as high as 2.86 wt.% Cr_2O_3 in one stone they analyzed) and, furthermore, may show high R.I. values (n_ε = 1.760–1.770, n_o = 1.768–1.780). The 1.19 ct ruby we tested had a chromium content and R.I. values that fall within the upper limits of those reported in that article, and its other internal characteristics were consistent with those reported for Mong Hsu stones. The above-referenced article by Peretti et al. also pointed out that heat-treated Mong Hsu rubies may contain glass-filled fissures, a feature that has resulted in their being misidentified as flux-grown synthetics. The high

Figure 8. A nearly colorless area can be seen at the base of this natural ruby cabochon (about 16.5 × 11.7 × 8.0 mm).

R.I. values of some Mong Hsu rubies may help separate them from flux-grown synthetics (which typically fall in the range 1.762–1.770).

This was the first of these high-R.I. rubies seen in the West Coast laboratory. Given what we know about Mong Hsu rubies and the quantities that are currently entering the marketplace, as well as the occurrence of Malawi rubies with high refractive index readings, we suspect that we will be seeing more high-R.I. stones in the future.

RCK and SFM

Two Stones with Unusual Features

A ring-set cabochon ruby (figure 8) seen recently in the East Coast lab had a near-colorless zone at the base. At first glance, it looked very much as if it was an area where dye had not "taken." Routine examination with a hand spectroscope revealed a typical ruby chromium spectrum, with no evidence of dye. Microscopic examination not only confirmed that the stone was natural with no dye, but it also showed that it had not been heat treated.

An attractive 9.57 ct natural star ruby with another anomaly was also seen in the East Coast lab. Not visible in the face-up view in figure 9 is an area on the bottom and part of one side that contained a soft, epoxy-like filling (figure 10). If the stone was carefully mounted, this area would probably not be seen and, in any event, it was undoubtedly deemed preferable in appearance to the large cavity that it filled. Although "glass"-filled cavities in ruby are not uncommon, this was one of the few instances we have encountered of a soft, epoxy-like filling in this gem material. *GRC*

SAPPHIRE, with Zoned Transmission Luminescence

Some gem materials luminesce when high-intensity visible light is transmitted through them, a feature gemologists call "transmission luminescence." In practice, we usually see this during routine gem testing with a desk-model spectroscope, which employs intense transmitted illumination, or when we use similar lighting to examine a stone with a Chelsea color filter. Gem materials that may exhibit this feature include natural and synthetic emerald, natural and synthetic ruby, synthetic alexandrite, synthetic blue spinel, and natural "cobalt" blue spinel. In all of these examples, the luminescence is an evenly distributed red. An exception is the green transmission luminescence of some diamonds, which normally occurs in fairly distinct planes or zones.

Figure 11. Red luminescence to intense transmitted light is confined to distinct bands, such as the one shown here, in this 19.45 ct blue sapphire. Magnified 20×.

In early 1995, the West Coast lab received for identification a 19.45 ct transparent blue mixed cushion cut. Routine gem testing identified the stone as a natural sapphire of natural color (that is, not heat treated or otherwise enhanced). When we examined this stone with a desk-model spectroscope, we were surprised to see a strong red luminescence that appeared to be unevenly distributed. When we used magnification in conjunction with a fiber-optic light source, it became clear that the luminescence was confined to distinct bands (figure 11). We then performed three EDXRF chemical analyses, with the stone at different orientations to the X-ray beam so we could measure different areas. One analysis

Figure 9. This 9.57 ct star ruby (about 14.05 × 9 × 7 mm) shows no evidence of cavity filling when observed face-up.

Figure 10. In this side view of the star ruby shown in figure 9, a large cavity with an epoxy-like filling is evident.

Figure 12. After only about three minutes' exposure to short-wave UV radiation during testing, this 4.57 ct near-colorless synthetic sapphire (left) turned brownish yellow (right).

revealed the presence of chromium, to which we attribute the visible-light luminescence. We surmise that the chromium is unevenly distributed in the stone, with the greater concentrations in those zones that show the unusual luminescence. *RCK*

SYNTHETIC SAPPHIRE, with Color Changed by UV Radiation

Laboratory irradiation has been used to change or develop color in many gem materials. Examples include the development of yellow in beryl, pink-to-red in tourmaline, blue in topaz, brown (the "smoky" color) in quartz, and various colors in diamond. (For more information, see K. Nassau's comprehensive *Gemstone Enhancement*, 2nd ed., 1994, Butterworth/Heinemann, Oxford, England, and C. E. Ashbaugh's "Gemstone Irradiation and Radioactivity," *Gems & Gemology*, Winter 1988, pp. 196–213.)

Radiation also causes yellow in corundum, but apparently more than one type of color center can be produced. Some radiation-induced yellow is stable to light (e.g., natural-color yellow sapphires from Sri Lanka and the yellow component of "padparadscha" sapphire). In other such sapphires, the color will fade on exposure to light. All such yellow color is faded by heat. For example, experimenting with synthetic sapphire, one of the editors has had a deep yellow induced in colorless synthetic sapphire and a pinkish orange produced in synthetic pink sapphire by exposure to radiation in a gamma cell. In both situations, it was found that the yellow color could be removed by gentle heating in the flame of an alcohol lamp.

In summer 1995, the West Coast lab received for identification a 4.57 ct transparent, near-colorless emerald cut, measuring 10.00 × 7.98 × 5.59 mm (figure 12, left). Gemological testing revealed refractive indices of 1.760–1.768, a birefringence of 0.008, and a uniaxial negative optic character—properties consistent with both natural and synthetic corundum. Magnification with various lighting techniques, including darkfield and brightfield, failed to reveal any inclusions or growth structures that could be used to determine whether the stone was natural or synthetic. Because we have had some success in resolving curved growth striae using magnification in conjunction with short-wave UV radiation (see, e.g., "Synthetic Sapphire, Another Striae-Resolution Technique," Winter 1994 Lab Notes, p. 270), we used this method to examine the stone. We successfully resolved curved striae, proving that it was a synthetic sapphire.

However, we were not prepared for the appearance of the sample when it was removed from the microscope's stage after the approximately three-minute examination: It had turned a medium brownish yellow (figure 12, right). Approximately six hours' exposure in a solar simulator removed most of the induced color, but the synthetic sapphire was ultimately returned to its original, near-colorless condition only by a few minutes of gentle heating in the flame of an alcohol lamp. This is the first instance we have encountered in which a yellow color was induced in corundum by such a relatively weak dosage of radiation.

RCK and SFM

Magnetic SERPENTINE

Many fine-grained translucent green materials may resemble jade—espe-

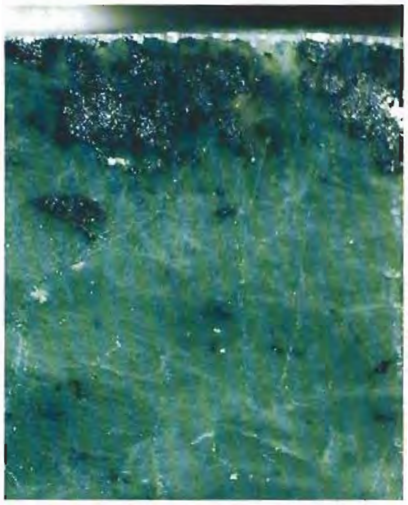


Figure 13. There were enough magnetite inclusions in this serpentine to attract the material to a magnet. Magnified 10×.

cially nephrite jade—at first glance. In August 1995, a semi-translucent, partially polished, green-and-black piece of rough material was submitted to the West Coast laboratory for identification. Aggregate gem materials such as rocks often require extra identification effort. Some properties (such as S.G.) represent averages of the components present, whereas other properties (such as R.I.) are representative of individual grains and not of the material as a whole. In the case of this rough material, we quickly eliminated nephrite as a possibility, but more work was required for positive identification.

We determined the following gemological properties: R.I.—about 1.57 (spot); S.G.—2.63; optic character—aggregate; fluorescence—mottled, with faint chalky blue areas, to long-wave UV and inert to short-wave. Weak absorption at 500 nm was visible through the hand-held spectroscope. With magnification, the material appeared soft, revealing a poor polish with many fine scratches and rounded edges on small fractures. The material also revealed an aggregate structure and black, equidimensional inclusions. Some brown areas, which looked like iron staining, were visible. All these properties were consistent with those of serpentine.

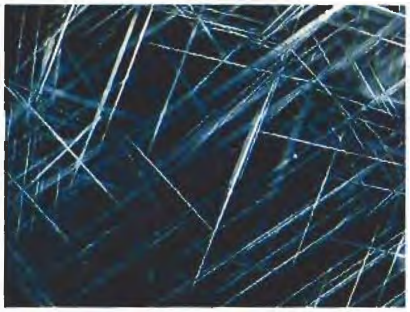
Our curiosity was piqued, however, by the black inclusions. Polishing of the piece had left a hackly (as if cut with a dull hacksaw) fracture exposed on some of these inclusions (figure 13). Using low-angle reflected illumination, we saw neither a white surface (as would be the case with a titanium oxide or ilmenite) nor a brown surface (as with hematite or pyrite). Attempts to rub the black material off on a piece of paper were unsuccessful, which indicates that it was not graphite. However, the fact that the piece was attracted to a hand-held magnet suggested that the inclusions were magnetite, a member of the spinel mineral group. This identification was confirmed by X-ray powder diffraction analysis of a small scraping taken from an exposed inclusion.

MLJ

SPINEL, with Högbomite(?) Inclusions

In February 1995, the West Coast lab received a 21.38 ct (19.24 x 14.78 × 9.28 mm) oval mixed-cut stone for identification. The stone was singly refractive, had a refractive index of 1.718, and was inert to both long- and short-wave UV radiation. Its absorption spectrum, as seen with a hand-held prism spectroscope, was typical for dark blue spinel.

Figure 14. The reflective "needles" (actually, thin plates) in this 21.38 ct color-change spinel may be högbomite, a mineral related to spinel. Magnified 15×.



Two features of this natural spinel were noteworthy: its color, which changed from violetish blue (in fluorescent light) to purple (in incandescent light), and its needle-like inclusions (figure 14). These inclusions—actually long, thin flat plates—formed in oriented aggregates in at least four different directions. On the basis of their appearance, GIA GTL's chief research gemologist John I. Koivula suggested that these plates might be exsolution lamellae (flat sheets) of högbomite, $(Mg,Fe^{2+})_2(Al,Ti)_5O_{10}$, similar to those reported by K. Schmetzer and A. Berger ("Lamellar Iron-Free Högbomite-24R from Tanzania," *Neues Jahrbuch für Mineralogie Monatshefte*, 1990, No. 9, pp. 401–412, and "Lamellar Inclusions in Spinels from Morogoro Area, Tanzania," *Journal of Gemmology*, Vol. 23, No. 2, 1992, pp. 93–94).

Högbomite comes out of solution in spinel as the crystal cools from high temperatures. According to Schmetzer and Berger, it has only been seen in gem spinels from the Morogoro area of Tanzania, although it is found in rock-forming spinels from other areas. Although Tanzanian högbomite is rich in titanium, no titanium was detected in this stone with EDXRF spectroscopy. We suspect that these exsolution plates are too small to affect the stone's overall chemistry.

MLJ

A TOPAZ Assemblage

The assembly of various materials to imitate gems has been with us throughout the centuries, dating back to Minoan and Roman times. Ancient writings such as the fifth century A.D. Greek *Papyrus Holmiensis*, and *Natural History* by Roman scholar Pliny (23–79 A.D.), have enlightened us on this practice (see, for example, the fascinating article by K. Nassau, "An Early History of Gemstone Treatments," in *Gems & Gemology*, Spring 1984, pp. 22–33). Doublets and triplets were very common imitations of such prized gems as ruby and emerald, at

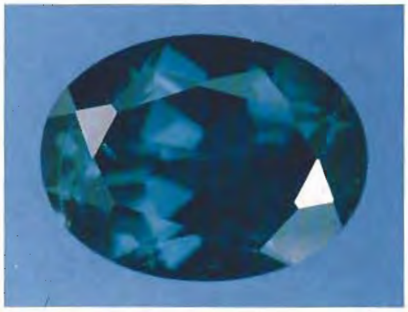


Figure 15. This 1.48 ct stone resembles some Paraíba tourmaline, but it is in fact a topaz triplet.

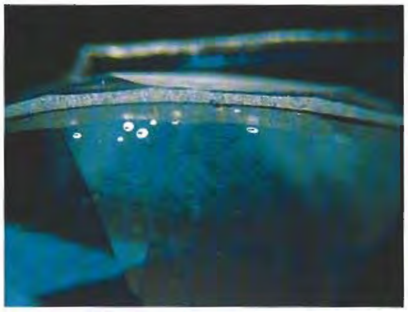


Figure 16. Magnification at 20×, with immersion in methylene iodide, reveals the separation plane at the girdle of the assembled stone in figure 15.

least until the advent of synthetics. The most common assembled stones GIA GTL has seen in recent years are opal doublets and triplets, as well as combinations of natural/synthetic corundum and natural/synthetic spinel. Much less frequently, we have also seen asteriated assemblages (see, for example, the Fall 1993 Lab Notes, p. 205).

Recently, however, the East Coast lab encountered a new type of assemblage, in a 1.48 ct faceted oval stone (figure 15). The color resembled that of some Paraíba tourmaline (see, e.g., the Fall 1989 issue of *Gems & Gemology*, p. 182, figure 8, second stone from the left).

Microscopic examination of the stone with immersion revealed that it was actually a triplet, composed of a near-colorless crown and pavilion held together by a greenish blue cement (figure 16). Refractive indices read about 1.60 to 1.61 (birefringence of 0.01) on both the crown and pavilion. Biaxial optic figures on both pieces confirmed that they were colorless topaz.

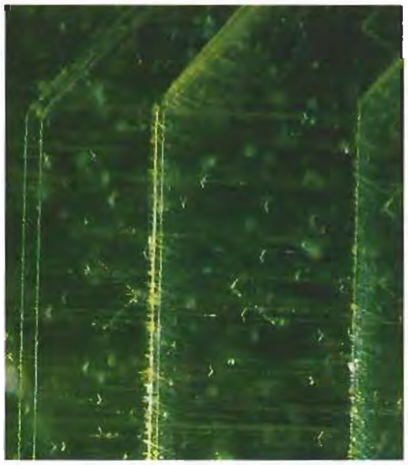
We can only speculate why this unusual triplet was created. However, Paraíba tourmaline of fine color and especially in larger sizes has become very scarce in the market and commands high prices; in addition, no synthetic tourmaline has been produced commercially as yet.

Nicholas DelRe

ZIRCON, with Phantom Planes

Sometimes, identifications are not particularly difficult, but a stone may contain features that are both photogenic and good teaching examples. Such was the case with a 9.24 ct green oval mixed cut that arrived in the West Coast lab early in 1995. Identifying it as zircon was straightforward: Strong doubling of the back facets was seen with magnification; the R.I. was over-the-limits of the standard gemological refractometer; the S.G. was 4.04 (measured hydrostatically); the stone was inert to long-wave UV and fluoresced faint green to short-wave UV; and its absorption spectrum (as observed with a desk-model prism spectroscope) showed "fuzzy" bands at 530, 580, and 650 nm (the last being the strongest). The stone was also slightly radioactive.

Figure 17. The decorated phantom planes in this 9.24 ct faceted zircon reveal much about its formation. Magnified 20×.



Magnification revealed an excellent illustrative set of inclusions: parallel zoning, V-shaped inclusions, skeletal inclusions (typical of low-property zircons), and especially angular zoning. The angular growth planes in figure 17 are probably the first- and second-order prism faces of zircon, {100} and {110}. At the time these faces were at the surface of the stone, they were being exposed to one or more episodes of deposition or dissolution (possibilities include the preferential deposition of solids or trace elements, dissolution of the zircon by fluids, or deposition of exotic material leading to *later* dissolution of the zircon). They appear as lines because the photo was taken looking parallel to the planes of these faces, that is, down the c-axis. These planes are decorated phantom faces.

An additional feature of these planes is that they reveal the relative growth rate of the two faces. The larger (longer) face ({100}?) grew more rapidly than the smaller face ({110}?), so the larger face became relatively shorter as crystal growth proceeded (from the bottom of the photo to the top). Although these features can be seen in many zircon samples, they are particularly well represented in this stone. *MLJ*

Erratum: *The 115.56 ct synthetic ruby described in the last Lab Notes section (Fall 1995, p. 203) was not produced by Czochralski pulling, but rather by a related proprietary technique.*

PHOTO CREDITS

Figure 1 was taken by Maha DeMaggio. The photomicrographs in figures 2, 11, 14, and 17 are by John I. Koivula. Shane McClure provided figures 3, 6, 12 (left and right), and 13. Nicholas DelRe supplied the pictures used in figures 4, 5, 7-10, 15, and 16.

GEM N·E·W·S

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THE 25TH INTERNATIONAL GEMMOLOGICAL CONFERENCE

New synthetics and gem localities, gem treatments, important jewelry collections, and advanced gem-testing methods were among the topics of over 30 presentations at this October's 25th International Gemmological Conference (IGC), held in Rayong, Thailand.

Official delegates from Australia, Belgium, Brazil, Canada, France, Germany, Hong Kong, India, Israel, Italy, Japan, the Netherlands, Singapore, Spain, Sri Lanka, Switzerland, Thailand, the United Kingdom, and the United States attended the conference, which was organized through the Asian Institute of Gemological Sciences, in Bangkok, by AIGS Director Kenneth Scarratt.

Each biennial conference takes place in a different country; every other one is held in Europe. The first IGC, organized by Professor K. Schlossmacher and Dr. E. J. Gübelin, took place in 1952 in Locarno, Switzerland. Since its inception, the purpose of this invitation-only event has been the exchange of information among laboratory gemologists and others engaged in the science of gemology.

The following entries are synopses of some of the presentations given at this year's IGC. Also included are reports on field trips taken in conjunction with the conference.

DIAMONDS

Fluid inclusions in diamonds. How some properties of fluid inclusions in diamonds are measured—and the types of fluid inclusions that have been seen—were explored in a talk by Dr. Oded Navon, senior lecturer at The Hebrew University, Jerusalem, Israel.

All the inclusions described were submicron in size and were found in regions of the studied diamonds that have a fibrous texture, including the outer shells of coated diamonds (figure 1). The internal structures of these inclusions were magnified by means of a transmission electron microscope (TEM), infrared spectroscopy was used to identify their individual constituents, and electron microprobe analysis was conducted to measure the average chemistry for each inclusion.

Thirteen diamonds from Botswana were found to contain inclusions of carbonates, apatite, a mica mineral, quartz, and a low-atomic-number noncrystalline phase (a hydrous fluid). All are probably daughter phases of the trapped potassium-rich parent melt. The internal pressures of the inclusions could be deduced from the shift in quartz (infrared) absorption bands from their positions at room temperature and pressure; the diamonds probably equilibrated at 40–70 kbar pressure (120–200 km depth) and retained pressures of 15–20 kbar in their inclusions.

Similar inclusions were found by Dr. Navon and his student, Marcus Schrauder, in fibrous diamonds from Zaire, India, Yakutia, and Sierra Leone. All were associated with the eclogitic paragenesis of diamonds. The researchers also found fluid inclusions in white cloud-like formations in some octahedral peridotitic diamonds from Yakutia. These inclusions also contained water and carbonates, but the solutes differed in composition.

Drs. Navon and Schrauder also discovered another type of fluid-bearing diamond, which contains solid carbon dioxide (CO_2; probably derived from carbonates). This type of diamond probably equilibrated at 70–80 kbar pressure (200–250 km depth), and still retained a pressure of about 50 kbar in the inclusions. CO_2-rich diamonds have been found in Yakutia and, recently, in the Sloan kimberlite on the Colorado-Wyoming border.

Some historical trends in the diamond industry. Dr. A. A. Levinson, of the University of Calgary, Alberta, Canada, reviewed historical trends—and changes in trends—in the diamond industry over the last century. Topics included changes resulting from major new discoveries (such as Russia, Botswana, and Australia); changes in the percentage

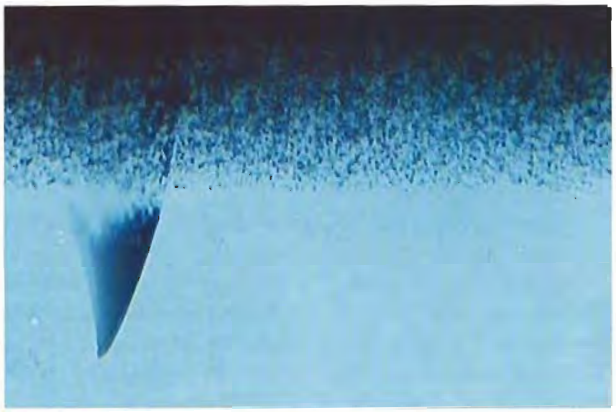


Figure 1. The edge of a densely packed cloud of tiny fluid inclusions is visible in this diamond at high magnification (400×). Photomicrograph courtesy of Oded Navon.

of production directly controlled by De Beers; economic and political factors affecting diamond production (including periods in which production virtually ceased in some mining areas); the importance of specific consumer countries (such as the United States and Japan); changes in jewelry consumption patterns (for instance, the increasing importance of jewelry other than the diamond engagement ring); the effect of low-cost Indian cutting on the retail diamond jewelry industry; and the move to develop new retail markets for gem diamonds, particularly in Asia.

An important upcoming change can be anticipated as a result of the potential development of diamond deposits in Canada's Northwest Territories. In about four years, an estimated two-to-three million carats (Mct) of diamonds—about 25% of which are gem—annually should be available to the rough diamond market, which currently consumes a total of about 100 Mct of diamonds per year, of which about 50 Mct are cuttable. These Canadian diamonds will come from several kimberlite pipes discovered since 1991 and owned by BHP (Australia) and Dia Met (Canada). Although details about the quality and size distribution of the diamonds have not been formally released, it is generally accepted that the gems "are considered to be of high quality, comparable to the best stones in the top ten pipes in the world" (Dia Met 1994 *Annual Report*, p. 5). The question then arises as to what, if any, effect this quantity of apparently high-quality gem diamonds will have on the diamond industry.

COLORED STONES AND ORGANIC GEM MATERIALS

New and unusual inclusions in amber and other gems. Gem News co-editor John I. Koivula described 16 new and unusual inclusions that he had recently examined. One item described, found in a 6.28 ct amber cabochon from the Dominican Republic (figure 2), was an anther (the pollen-bearing part of a flower stamen) from the extinct tree *Hymenaea protera* of the *Leguminoseae* family, which produced the resin that fossilized to form much of the amber from this region. Magnification revealed a small insect (*Thysanoptera*, or thrip) that was trapped in the anther's pollen slit along with numerous tiny pollen grains (figure 3).

Also described was a collection of iolite pebbles (from Sri Lanka and Madras, India, gathered over 25 years) that contained blue-green inclusions of sapphirine. Mr. Koivula also illustrated a very rare, transparent blue inclusion in a diamond, which he speculated might be kyanite. Also shown was an inclusion pattern resembling ink droplets against a swirled yellow background. The host was a very pale yellow hessonite from a new locality for this gem: Tissamaharama, Sri Lanka. The inclusions are actually blue-green spinel octahedra that, because their refractive index is similar to that of the host, show very low relief.

Green beryl and emerald from Central Nigeria. Dr. Charles Arps and Hanco Zwaan, from the National Museum of Natural History and the Netherlands Gemmological Laboratory in Leiden, examined 170 pieces of rough and about 20 cut stones from two areas of central Nigeria: one east of Gwantu (southeastern Kaduna State), and the other northwest of Nassarawa Eggon (Plateau State). They investigated these nearly 200 beryls with regard to crystal habit, growth features and inclusions, physical constants, color, and chemical composition.

The crystals were recovered by primitive open-cast mining techniques from fissure fillings and pegmatitic stringers and veins occurring in the strongly weathered granitoid basement rock, which consists of migmatites, amphibolites, and various gneisses and schists. In many places in central Nigeria, these Precambrian rocks are cut by Late Precambrian granite intrusions (Older Granite) and granites of Cretaceous age (Younger Granite complexes). The widespread occurrence of ores (tin) and other minerals (such as topaz, aquamarine, and tourmaline) is associated with the emplacement of these granite complexes (mainly the Younger).

Green beryl and emerald in the Gwantu and Nassarawa Eggon deposits are very likely the crystallization products of beryllium-, chromium-, and vanadium-bearing hydrothermal or pegmatitic solutions that impregnated the basement rocks near the Younger Granites. Evidently, the presence of chromium and vanadium ions in the salty brines is explained by the fact that the fluids passed through Cr- and V-bearing mafic/ultramafic "greenstones" present in the basement rock.

Many of the rough beryls studied were relatively long and slender hexagonal prisms with strongly etched crystal faces. Some crystals were irregular or broken at both ends, but others had well-developed pyramidal and pinacoidal terminal faces. The nature of the zoning, together with two- and three-phase inclusions, clearly pointed to crystallization in a hydrothermal or pegmatitic environment. No inclusions that would indicate growth of the emeralds in the mafic/ultramafic rocks themselves were encountered.

Most of the samples ranged from near-colorless and pale green to medium-dark bluish green. They displayed marked color zoning both parallel and perpendicular to the c-axis. Strong zoning parallel to the *c*-axis, characterized by a relatively narrow colorless flawed rim and a transparent (yellow- or bluish) green core, is typical for the Nigerian beryl crystals. Twelve faceted stones (1.84 to 28.66 ct) had specific gravities between 2.672 and 2.686, and refractive indices of 1.560 to 1.567 (extraordinary ray) and 1.565 to 1.572 (ordinary ray). UV-visible absorption spectra of the samples showed two different patterns: (pale) green beryls displayed a stronger presence of iron relative to chromium, whereas chromium was more pronounced in the medium-dark stones. These results indicated that good-color emeralds also occur in the Gwantu and Nassarawa Eggon deposits. Chemical analyses of pale green emerald indicated that, besides chromium and iron, vanadium is present as a coloring agent. The calcium, sodium, and potassium contents are very low compared to emeralds from other deposits.

Red beryls from Utah. Dr. Frederick Pough, of Reno, Nevada, gave an overview of red beryls from Utah's Wah Wah Mountains. The red beryls are found just to the south and west of the Thomas Mountains in Utah, one of the many north-south-trending mountain ranges that comprise the Basin and Range geologic province of the western United States.

The red beryls in the Wah Wah Mountains are concentrated in seams in white rhyolite. They apparently grew in both directions from a central seed plate: Usually crystals appear to have a break through the middle of the stone, with the two parts not perfectly aligned. Inclusions are plentiful in the cut stones, which usually weigh less than 1 ct; the largest stone faceted to date is about 7 ct.

Since this is a single-source gemstone (mined only in the Wah Wah Mountains) that is a variety of a well-recognized gem material (unlike tanzanite at its first introduction), Dr. Pough thinks that the marketing economics look good. He thanked Rex Harris, the miner of the material, for his generous cooperation.

Gem localities in China. Professor Akira Chikayama, of the A. Chikayama Gem Laboratory in Tokyo, Japan, presented an update on gem localities in China, based on his extensive travels there.

Diamonds are found at Wafangdian in Liaoning Province, Mengyin in Shandong Province, and Yuanjiang in Hunan Province; rubies at Yuanyang and Yuanjiang in Yunnan Province; sapphire at Changle in Shandong Province and Wenchang on Hainan Dao Island; emeralds at Yuanyang and Wenshan, Yunnan Province; and aquamarines also at Yuanyang, Yunnan Province, and at Altay, in Xinjiang Uygur Autonomous Region. (Altay also produces almandine garnets, topaz, tourmaline, zircon, amazonite, and rose quartz.)

Peridot is found at Zhangjiakou, Hebei Province, and at Beishishan, Jilin Province. Gem materials found elsewhere in China include: topaz, tourmaline, zircon, garnets (pyrope, almandine, and grossular), nephrite, fluorite, quartz varieties (rock crystal, amethyst, rose quartz, tiger's-eye, green jasper, and green, white, and blue quartzite), rhodonite, turquoise, malachite, amazonite, serpentine, pyrophyllite (some with cinnabar inclusions), lepidolite, dolomite, saussurite, "chrysanthemum stone," and ore minerals (hemimorphite, smithsonite, and cinnabar).

Colored stones seen by CISGEM Laboratory. Dr. Margherita Superchi presented examples of identification problems recently seen by herself and co-workers at the CISGEM Laboratory (Chamber of Commerce, Milan, Italy).

Certain pink freshwater pearls and red coral were shown to have natural (for the pearls) and stain-induced (for the coral) colors based on the presence or absence of Raman spectral peaks for carotenoids, which cause the pink and red colors in some organic materials.

Figure 2. This 6.28 ct cabochon of Dominican amber contains an anther from the extinct tree Hymenaea protera. *Photo by Maha DeMaggio.*

*Figure 3. A closer look at the anther shown in figure 2 reveals a tiny insect (*Thysanoptera*) trapped in the pollen slit. Photomicrograph by John I. Koivula; magnified 15×.*

A new rock, promoted as violet jade, does contain jadeite. A Russian hydrothermal synthetic emerald (containing Ni and Cu, but not V) that lacked a flame structure was identified on the basis of its FTIR spectrum. Light-yellow glass "grown" on a white ceramic "rock" contained high levels of Zn and As (it had an R.I. of 1.48 and several sizes of included gas bubbles). Last, a hardened epoxy resin in a natural emerald could be distinguished from several other natural and synthetic resins, including unhardened epoxy resin, based on its Raman spectrum.

New gem deposits in Shan State, Myanmar. Northeastern Myanmar is famous for its corundum deposits, including both the Mogok Stone Tract and the Mong Hsu area in Shan State. While visiting that state's capital, Taunggyi, one of the editors (RCK) learned of another promising corundum deposit from U Tin Hlaing, professor of geology at Taunggyi University. Professor Hlaing reported that the deposit is located about 100 km (62 miles) northeast of Taunggyi. It is reached by walking some 9 km (6 miles) northwest from the town of Lai Hka, which takes about one-and-a-half hours. The corundum—primarily pink sapphires—is found with pink-to-red spinels in a marble horizon in about the center of a metamorphic belt running roughly 130 km north-south by 1.5 km (about one mile) wide. Sapphires are also found in associated alluvial deposits. Professor Hlaing believes that corundum may have been found in the area as early as 1989, but it was not recognized as a new deposit because the stones were mixed in with Mong Hsu material in the Taunggyi gem market.

Recently, garnets have been found at Mong Kung, about 35 km (22 miles) north-northwest of Lai Hka, at the eastern edge of the metamorphic belt. Both ruby and spinel have been found in an area between the towns of Lang Hko and Mawk Mai, approximately 28 km east-southeast of Taunggyi.

New emeralds from southern India. A 15-km-long belt of micaceous rocks "near the Idappadi and Konganapuram village of Sankari Taluka" in the Salem district, Tamil Nandu State, India, is the site of a new find of emeralds, according to Dr. Jayshree Panjikar, of the Gemmological Institute of India, Bombay. She and her colleagues examined 16 samples, ranging up to 23.05 ct. They found that these Sankari emerald crystals occur as hexagonal prisms (figure 4), with pyramidal faces and sometimes second-order prism faces.

They determined the following gemological properties: color—saturated green to "pale whitish green"; pleochroism—medium to strong, bright green (parallel to the c-axis) and bluish green (perpendicular to the c-axis); S.G. (hydrostatic)—2.70 to 2.73; R.I.—1.582 to 1.585 (extraordinary ray), 1.588 to 1.591 (ordinary ray); birefringence—0.006; and spectrum with a hand-held type of spectroscope—strong doublet at 680 nm, fine line at 630 nm. With a spectrophotometer, they detected Cr^{3+} peaks at 684, 676.8, 629, and 611 nm; Fe^{3+} peaks at 368.8 and 453 nm; (possibly iron or vanadium) peaks at 504, 530, and 568 nm; and, in darker stones, additional peaks between 400 and 500 nm.

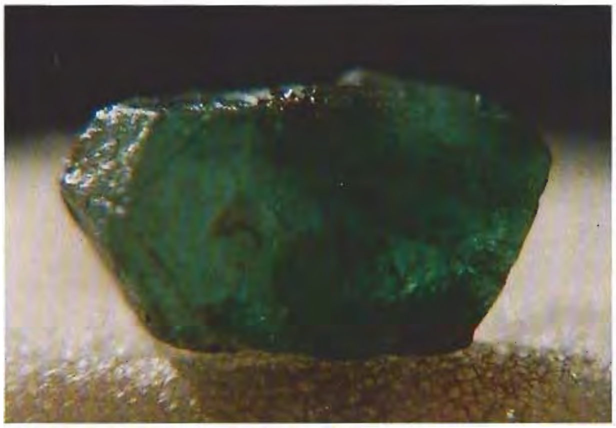


Figure 4. This emerald crystal, approximately 10 mm wide, is typical of the color and shape of emeralds from a new find in southern India. Photo by Jayshree Panjikar.

The dark green stones had slightly different chemistries (determined by atomic absorption spectroscopy) and fluorescence behaviors than their pale green counterparts. One dark green stone contained 0.92 wt.% Cr_2O_3, 0.46 wt.% Fe (as FeO), and 0.02 wt.% V_2O_3. A pale green stone contained 0.56, 0.03, and 0.03 wt.% of these elements, respectively.

Among the inclusions seen in Sankari emeralds were mica (most common), quartz, apatite (figure 5), feldspar, pyrite, included hexagonal beryl crystals (visible in polarized light), spinel, black rounded crystals with tension cracks, large needle-like inclusions (possibly tourmaline or amphibole), and black carbonaceous matter. Two generations of fluid inclusions were seen, with some three-phase inclusions in negative crystals among the first generation. Remarking on the resemblance of these stones to emeralds from Madagascar, Dr. Panjikar suggested that both deposits may have come from the same (Precambrian to early Cambrian) metamorphic belt, split in two with the breakup of the ancient supercontinent Gondwanaland. Because of this, she thinks that there is a possibility of finding large deposits of emeralds and other gemstones in the area.

Natural glass: tektites. Dr. Charles Arps, of the National Museum of Natural History in Leiden, presented an overview of tektites, their occurrences, morphology, properties, identifying characteristics, and uses.

He described tektites as relatively small shiny black to dark brown or green semitransparent natural glass objects, with characteristic but variable shapes, symmetry, and surface morphology. Tektites have been found in four "strewn fields," or regions: Southeast Asia/Australia, Czechia in Central Europe, the Ivory Coast of West Africa, and south-to-southeastern North America. Although several theories have been proposed for the formation of tektites, most geochemical evidence is consistent with their origin as the

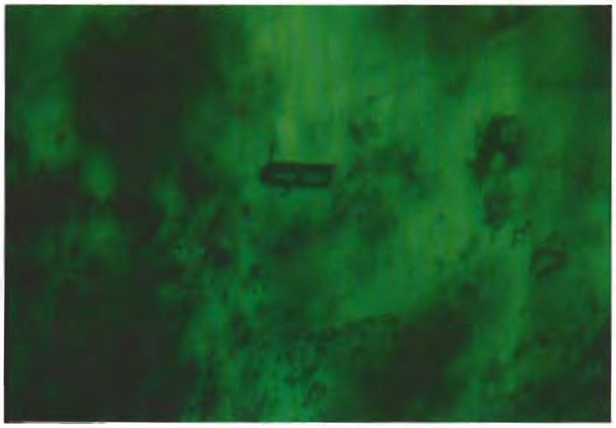


Figure 5. Tiny apatite crystals are among the mineral inclusions found in the new emeralds from southern India. Photomicrograph by Jayshree Panjikar; magnified 50×.

ejected residue of terrestrial rocks that were blasted by meteorite impacts. (In fact, two of the strewn fields are associated with individual craters: Czechia with the Ries impact crater in southern Germany, and Ivory Coast tektites with the Bosumtwi crater in Ghana.) The Australasian tektites are the youngest, 720,000 years old; the Ivory Coast tektites are 1.02 million years (My) old; the moldavites (tektites from Czechia) are 14.7 My old; and the North American tektites are the oldest, at 34.2 My.

Tektites have varietal names based on their shapes as well as on their provenances. For instance, in the northwestern part of the Australasian strewn field, "splash-form" aerodynamic-looking tektites (ovals, dumb-bell shapes, teardrops, buttons) are distinguished from the irregular, chunky, and sometimes very large Muong Nong tektites. Other names include: moldavites (tektites from Czechia); bediasites and georgiaites (tektites from the U.S.); and indochinites, philippinites (or rizalites), billitonites, javanites, and australites from various parts of the Australasian strewn field.

As cut stones, tektites can be difficult to distinguish from manufactured glass. (Moldavites were originally believed to be slag from the Bohemian glass-making industry!) Among the characteristic inclusions of this natural glass are: gas-filled bubbles and vesicles, a strongly contorted swirling internal structure, small grains or curved tails of isotropic "lechatelierite" (pure silica glass), Fe-Ni spherules, and shocked mineral inclusions. R.I.'s fall between 1.48 and 1.53, and S.G.'s are 2.30–2.52. Tektites vary widely in chemistry, with both R.I. and S.G. increasing as the silica content decreases.

Tektites have been used since prehistory as ornamental materials and gems, as tools, and as cultural and religious objects (in Europe, Thailand, and West Africa). In some Australian tribes, they were regarded as magical. However, miners in Indonesia have considered them bad omens in certain alluvial deposits.

Jade market in Mandalay. Although jadeite has been found in a number of countries, including Guatemala and Russia, the major commercial source of this important gem material is Myanmar (Burma). The main mining area in Upper Burma is situated between Hpakan and Tawmaw, near the Uru River. While some jadeite leaves the mining areas via China, most of the rough material travels south to the city of Mandalay.

In conjunction with the IGC conference, one of the editors (RCK) visited the open-air jade market in Mandalay. He found most activity to be centered on 86th Street, between 38th and 40th Streets. On what was described to the editor as a typical business day, easily 5,000 people, buying and selling goods, packed a 500 m stretch of street and a large nearby courtyard (close to the 40th Street intersection). At the opposite end, near 38th, in an open area adjacent to the Ah Yoe Ooe pagoda, dealers were selling almost exclusively "utility jade." This material, typically used for carving ornamental objects such as figurines and functional objects like bowls, was sold in such forms as small boulders, unpolished slabs, slab fragments (including the peripheries of pieces from which hololith bracelets had already been cut), and lower-quality hololith bracelets (figure 6). Elsewhere along the street, dealers sold low- to high-quality "commercial jade"—gem-quality material suitable for jewelry items and less-valuable gemstones.

The fine-quality "imperial jade" was seen in another jade market, along 34th Street between 85th and 86th Streets. Here, we saw far fewer buyers and sellers, not more than 200 total. Unlike the larger market, nothing was

Figure 6. At one end of the jade market in Mandalay, Myanmar, a woman sells fragments of jadeite slabs and other lower-quality material. Photo by Robert C. Kammerling.

Figure 7. In a small lapidary shop in Mandalay, Myanmar, a worker saws a double ring blank in half to produce ring "preforms." Photo by Robert C. Kammerling.

openly displayed. When approached, dealers would take small stone papers from pockets or from inside their shirts. Almost all the material seen in this market was of very good to excellent quality. Although most were cabochons, one dealer offered gold rings, each set with a single imperial jadeite cabochon.

Jadeite lapidaries in Myanmar. While Myanmar is the major commercial source of jadeite, most is fashioned elsewhere, especially Hong Kong and southern China, as well as various cities in Thailand.

Still, some Myanmar jadeite is cut in the country itself. While in Mandalay, one of the editors (RCK) visited several small shops in what appeared to be essentially a cottage industry. One had a single electric-motor-driven saw, which was being used to cut an approximately 1 kg boulder. The piece had been purchased "mawed," that is, with a single window ground into its surface. The buyer, a master with 30 years of jade buying and cutting experience, had used this window to inspect the interior before purchase. Under the watchful eyes of this master, an assistant cut sections off the boulder. After each cut, the master would examine the remaining block and mark it with a pencil, indicating where the next cut should be made. The cutting revealed that the boulder was about one-third imperial jadeite, with the rest commercial jadeite. From the better portion, the firm estimated that it would recover 20%–25% of the weight in fashioned goods. If their estimate proved accurate, they expected to double their $25,000 investment.

The next shop visited produced blanks for jadeite hololith bracelets (the final shaping and polishing was apparently done elsewhere). Jadeite boulders were first cut into slabs on an electric saw. After that, the hololith blanks were cut out using a drill-press-like machine with two concentric circular blades.

Another shop produced two types of finished items from the central cores remaining after hololith bracelets were cut from jadeite slabs: small hololiths for infants' bracelets and for stringing together to make jadeite curtains, and hololith rings. For the rings, a double-bladed cutting tool was again used to cut three double blanks from each circular blank. Each double blank was then sawn in half, producing two ring "preforms" (figure 7). We were told that the workers shared 2 kyats (about US$0.02) for each preform produced. They produced the ring's final, rounded shape by rotating it on the shaft of a lathe while bringing into contact a fist-sized piece of basalt; for this step, a worker is paid 1.5 kyats (about US$0.015) for each ring. Another worker polished the ring on the lathe, using the outer surface of a piece of bamboo; again, the pay was 1.5 kyats. We were told that one worker responsible for the last two steps could typically produce 50–60 rings a day.

One of the most interesting shops carved jadeite from designs created by an artisan-carver or copied from a previously fashioned piece or from an illustration. As an example of the latter, the editor was shown a photo of a bronze statue of a deity. From this, an acetate template was made with the outlines of the statue. The template was then traced on a sawn "face" that had been placed on a small jadeite boulder (see, e.g., figure 8). All of the artisans at this shop had some art training as well as experience as woodcarvers or in carving softer gem materials such as alabaster. Even with this experience, they had all traveled to China to learn how to work jade.

Tools used to work the jadeite include electric grinding wheels and hand-held drills. All the actual cutting tools had been made in the shop. The coarsest abrasive for the grinding wheels was prepared from Carborundum powder that had been mixed with a hard waxy material secreted by tree-boring insects. The finer-grit abrasive was made from a mixture of this waxy material and ground, petrified wood. For the final polish, a commercial dental polishing compound was used, although the firm was experimenting with a diamond powder purchased from China. Using this equipment, in five days an artisan can fashion one 25 cm–tall image of the Buddha or 10 small pendants. The firm charges from 1,000 to 5,000 kyats (US$10–$50) per cubic

Figure 8. A partially-carved image of the Buddha (left) awaits final carving and polishing. Black ink marks how a sawn jadeite boulder will be carved (right). Photo by Robert C. Kammerling.

inch for carving statues. (The exact amount depends on the intricacy of the design.)

We also visited a shop that produces jadeite cabochons. The cabochons were first rough ground on a vertical grinding wheel, then preformed on a finer-grit wheel. The last step, polishing, was performed with a wide lathe shaft that was covered with bamboo (figure 9). Unlike the other shops visited, the equipment here was powered by foot pedals.

Figure 9. One worker polishes a jadeite cabochon using a wide lathe shaft covered with bamboo (left), while the other worker preforms a cabochon on a grinding wheel. Photo by Robert C. Kammerling.

The last stop was at a firm that produced beads. Workers formed them by hand on a grinding wheel. The beads were then drilled with a bow drill, the cutting tool for which was a rod tipped with a small diamond crystal. The other end of the rod was manipulated by the driller. We were told that it takes about five minutes to completely drill a 6–9 mm bead. Workers were paid 2 kyats (US$0.02) per drilled bead.

Freshwater natural pearls from the Lac St. Jean area, Québec. Francine Payette, a geologist-gemologist from Québec, Canada, examined the structure and composition of three pearls from the pearl mollusk *Margaritifera margaritifera*, which is found in some Québec waterways and in a limited area along the Atlantic Coast. (The natural range distribution of this mollusk extends from Labrador to Pennsylvania, along the East Coast drainage of North America.)

Young *M. margaritifera* live as parasites on brown and spotted trout in Québec rivers. Adults live in the mud and sand on the bottoms of small waterways; they grow shells up to 4 × 6.5 × 15 cm, with brown-to-black exteriors and white (with tints of pink and violet) nacre. There is no commercial pearl fishing in the province, and the cold climate limits harvesting to about four summer months.

Ms. Payette, who performed her analyses at the Laval University Department of Geology in Québec, used cathodoluminescence, X-ray diffraction analysis, scanning electron microscopy, and optical microscopy to study thin-sectioned samples of these pearls. Aragonite was the main mineral component, with minor calcite detected. In the interior of the pearl, the aragonite occurs as long, slender crystals radiating from a central point; in the thin outer layer, the aragonite occurs as tabular crystals (figure 10). The contact zone between these two layers is quite sharp; in the nacreous layer, the tabular aragonite crystals overlap one another, with some disordered layering seen. One non-nacreous concretion showed partial dissolution (diagenesis?) of the exposed square cross-sections at the ends of the radiating aragonite crystals, with small calcite(?) crystals between them. Ms. Payette speculated that the small amounts of calcite may have been responsible for the cathodoluminescence of these pearls, which was more sporadic in the nacre layers. She cautioned that more work is needed, and noted that some Québec pearls were also described by Dr. Emmanuel Fritsch in the Spring 1993 Gem News (p. 58).

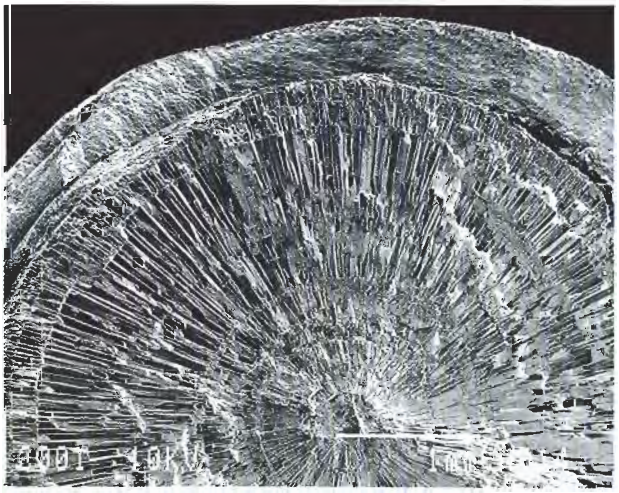
Unusual pearls. Although today's commercially important pearls predominantly come from a small group of nacreous salt- and freshwater bivalves, niche markets do exist for rare pearls, such as gastropod-derived abalone and conch "pearls," and bivalve-derived wing-shell pearls. However, some pearls are rarer still. Dr. Grahame Brown, of ALL-

GEM Services, Albany Creek, Australia, reported on some rare and unusual pearls that he had seen over the last two decades. He described:

- A hammer-oyster (*Malleus albus*) "pearl", which was brownish, pear shaped, and non-nacreous. It had an S.G. of 2.2 and was formed from alternating layers of radiolucent conchiolin and radiopaque calcite.
- A brownish nacreous button pearl discovered in a saltwater (edible) New Zealand Greenshell™ mussel (*Perna canaliculus*).
- A bicolored near-hemispherical button pearl, with striking (and characteristic) orient and luster, from the black-banded wing shell, *Mangavicula macroptera*.
- A porcelaneous clam "pearl" from *Tridacna gigas* of Papua New Guinea origin—a distorted pear-shaped opaque white concretion with an S.G. of 2.80 and no structural characteristics visible with X-radiography.
- "Coconut pearls" (figure 11), which are manufactured by Indonesian craftsmen from processed thick shell, and which show characteristic striations with "transillumination."
- Highly iridescent natural abalone pearls and cultured abalone half-pearls, with silvery green to brownish red subsurface colors that continuously shifted as the pearls were moved under indirect overhead illumination.
- An extremely rare *trochus* "pearl" (from *Trochus niloticus*), which displayed a porcelaneous luster but had the typical concentric lamellar structure of a natural pearl.

Dr. Brown also described an early cultured pearl necklace of Australian origin. Evidence suggested that the pearls were cultured in the Australian *P. maxima* during or before the first decade of the 20th century, by the Englishman William Saville-Kent. Mr. Saville-Kent operated a pearl-culturing farm on Albany Island, just to the east of Australia's Cape York, between 1906 and 1908. Dr. Brown proposed that Mr. Nishikawa and Mr. Mise, generally accepted as the first to culture round bead-nucleated pearls successfully, may have learned the technique by observing Mr. Saville-Kent's experiments on or around Thursday Island.

Figure 10. This SEM photomicrograph clearly illustrates the long aragonite crystals radiating from the core, and the outer layer of tabular aragonite crystals, in a natural pearl from the Lac St. Jean area, Québec. Photomicrograph courtesy of the Department of Geology, Laval University, Québec, Canada.



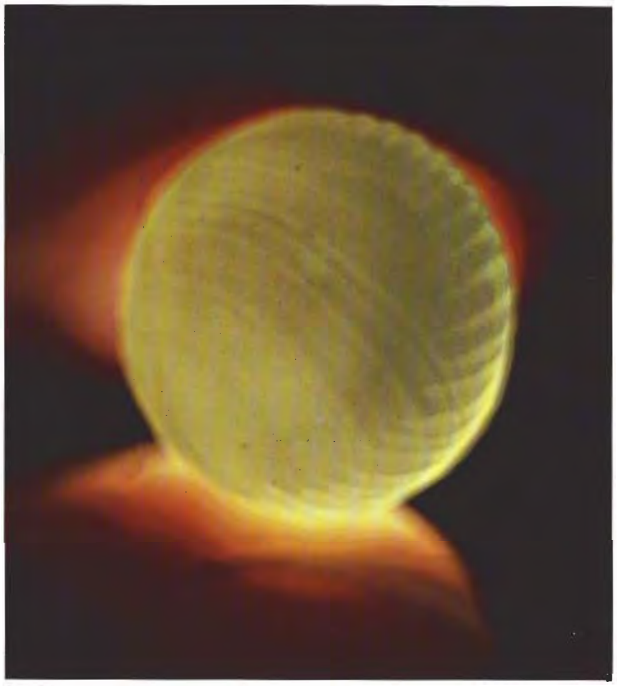


Figure 11. This 13 mm "coconut pearl" was manufactured in Indonesia from a thick piece of mother-of-pearl shell. Transillumination ("candling") reveals the shell structure and cutting marks. Photo courtesy of Grahame Brown.

Rubies from the Barrington volcanic field, East Australia. Dr. F. L. Sutherland, of the Australian Museum in Sydney, described faceting-quality rubies found in alluvial deposits shed from the Tertiary Barrington basalt shield volcano in eastern Australia. The rubies accompany sapphire, zircon, spinel, and other heavy detrital minerals (figure 12). Crystals show corrosion from transport in a hot fluid; the main mineral inclusions in these crystals are pleonaste (ferroan spinel) and chromian pleonaste. The ruby grades into pink sapphire with a decrease in chromium and iron contents.

The parent rock—found as small mineral aggregates accompanying the gem corundum—contains ruby, sapphire, sapphirine, and spinel, with a reaction-rim of pleonaste spinel (from transportation in a hot melt) sometimes visible. Sapphires that crystallized with the ruby are near-colorless, or are found in pastel shades of yellow, blue, green, or pink. The sapphirine is usually blue to green, with a composition of about $7MgO \cdot 9Al_2O_3 \cdot 3SiO_2$ with some iron substitution. The spinel is opaque pleonaste and chro-

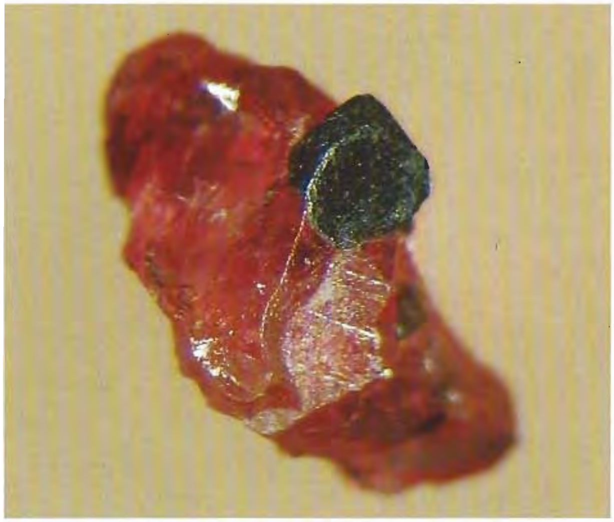


Figure 12. This 3 mm–long ruby grain with attached chromian spinel crystal is from the Barrington volcanic field in eastern Australia. Photo by Gayle Webb; © Australian Museum, Sidney.

mian pleonaste. Sapphirine-spinel thermometry suggests that these aggregates crystallized at about 780°–940°C.

This suite of associated minerals contrasts with the more common sapphire suites in eastern Australia, which typically contain blue-green growth-zoned sapphire crystals. Such sapphires contain inclusions of rutile (silk) and iron-rich spinel, as compared to the pleonaste inclusions in the Barrington corundum aggregates. The association with sapphirine seen at Barrington also appears in some alluvial ruby fields in Thailand (Rubywell mine). This raises the potential of sapphirine as an indicator for ruby sources.

Figure 13. Two young women sort rough rubies from Mong Hsu at the gem market in Taunggyi, Myanmar. Photo by Robert C. Kammerling.

Ruby market in Taunggyi. For many of the rubies mined in Mong Hsu, the first stop after the mines is the ruby market in Taunggyi (Myanmar). In early November 1995, in conjunction with the IGC conference, one of the editors (RCK) visited this important gem-trading center.

Located near the outskirts of the city, the market is in an enclosed compound reminiscent of (but larger than) that at Luc Yen in northern Vietnam. For the most part, dealers sit at small tables (figure 13), for which they pay 200 kyats (about US$2) a day. Even though business was described as "light" on the day we visited (which followed a holiday), we conservatively estimated that some 2,000 people were in the compound at the height of activity. We were told that 10,000 people typically crowd the market on a more normal work day, but that this is half the number seen the previous year.

This drop in activity apparently does not relate to problems in Mong Hsu: Several people confirmed that there has been no decrease in mining activity, and material continues to move freely to Taunggyi. Rather, the market reportedly has been affected by a drop in the prices paid for Mong Hsu material, because of increased difficulties in getting it out of the country. In the past, material freely crossed from Tachileik, Myanmar, into Mae Sai, in the far north of Thailand (see "Update on Monghsu ruby," Winter 1993 Gem News, pp. 286–287). However, about six months before the editor's visit, the Myanmar government closed this land link. Material now travels a more circuitous, and perhaps less-secure, route from Myanmar into Thailand. We were told that much of the Mong Hsu material was being diverted to the Thai border towns of Mae Hong Song and Mae Sot.

Although rubies dominated the Taunggyi market, we also noted small parcels of blue sapphire (reportedly from Mogok), some non-gem tourmaline, spinels from both Mogok and Mong Hsu, a few pieces of fluorite (both violetish blue and green) from Mogok, commercial-quality jadeite cabochons, and red garnets from the Mong Hsu area. We were also told that some of the higher-quality Mong Hsu material is sent to Mogok, because material of Mogok provenance brings a higher price on the market. Conversely, lower-quality Mogok material is brought to Taunggyi and mixed in with that from Mong Hsu.

As many as one-third of the women in the market wore gem-set jewelry, primarily earrings and large pendants set with many small, faceted rubies (figure 14). When asked the source of their stones, most said that it was Mong Hsu.

Sapphire mining in Laos. Southeast Asia is famous for its corundum deposits: Myanmar has Mogok and Mong Hsu; Thailand has Kanchanaburi and Chanthaburi-Trat; and Cambodia has Pailin. The newest addition to this group of corundum producers is Laos. In a brief report in the December 1994 *ICA Gazette*, a Laotian locality called

Figure 14. This woman, like many of those buying and selling gems in the Taunggyi market, wears ruby-set earrings. Photo by Robert C. Kammerling.

"Huai Sai" was said to produce good-color blue sapphire. More recently, in the August-September 1995 issue of *JewelSiam*, David Squires described a brief visit to a mechanized mining operation near the Laotian border town of Ban Houay Xai.

Also in conjunction with the IGC conference, one of the editors (RCK) visited a mining area not far from Ban Houay Xai. Starting from the city of Chiang Rai in northern Thailand, the editor and a few colleagues drove approximately one-and-a-half hours on a paved two-lane road to reach Chiang Khong, a Thai border town on the Mekong River, roughly 70 air miles (112 km) northeast of Chiang Rai. After arranging for a one-day entry permit to enter Laos, the group crossed the river by long, narrow power boat to Ban Houay Xai, where we rented two "samlors" (motorcycle taxis) for the drive to the mines.

The first site visited was Ban Tong Saeng Chan, which translates as "field with moonlight," about 15 km southeast of Ban Houay Xai. The mining area was a large field that had been pierced by circular shafts about 1.5 m in diameter and 2–3 m (6–9 feet) deep. Miners reached the bottom of the shafts by climbing down bamboo poles. They used short-handled shovels to dig the shafts (and sometimes short tunnels—no more than a meter or so—into the gem-bearing layers). Miners used either the shovels or small metal bowls to extract the gem-bearing lateritic soil (we saw no distinct gravel layer in any of the pits). The extracted material was then placed in a bucket and, in shallow shafts, handed to a co-worker at the surface (figure 15). When the shaft was too deep, the miners hauled the buckets to the surface using a bamboo pole fitted with a hook on one end.

When enough material had been extracted, it was sifted through a large-mesh basket to remove any large rocks and then loaded into a plastic grain sack, which the miner then carried to a small stream some 200–300 m away. Here, the soils were shoveled into wide, shallow woven wicker baskets, like those used in many parts of the world for washing gem-bearing material. Because the stream was very shallow, the miners used shovels to dig depressions in the stream bed deep enough to permit washing. Once the soil had been washed away, the miners would examine the gravels and remove any sapphires found, often while still sitting in the stream (figure 16).

The editor had an opportunity to briefly examine some of the sapphires, both at the washing site and at a local dealer's home. These sapphires ranged from light to dark blue (figure 17), with many noticeably color zoned. The overall impression was that some fine-quality material was coming out of the area. Although most of the rough was small (one carat or less), we saw some stones of several carats.

The sapphire deposit in southern Madagascar. Sapphires from new mining operations near Andranondamtso, Madagascar, were described by Contributing Editor Dr. Henry Hänni, on the basis of work done with colleagues Michael Krzemnicki and Drs. Lore Kiefert, Karl Schmetzer, and Heinz-Jürgen Bernhardt. Andranondamtso is a small village north of Tolanaro (Fort Dauphin).

Figure 15. At a sapphire-mining locality near Ban Houay Xai, Laos, a miner passes a bucket of soil and gravel to a co-worker. Photo by Robert C. Kammerling.

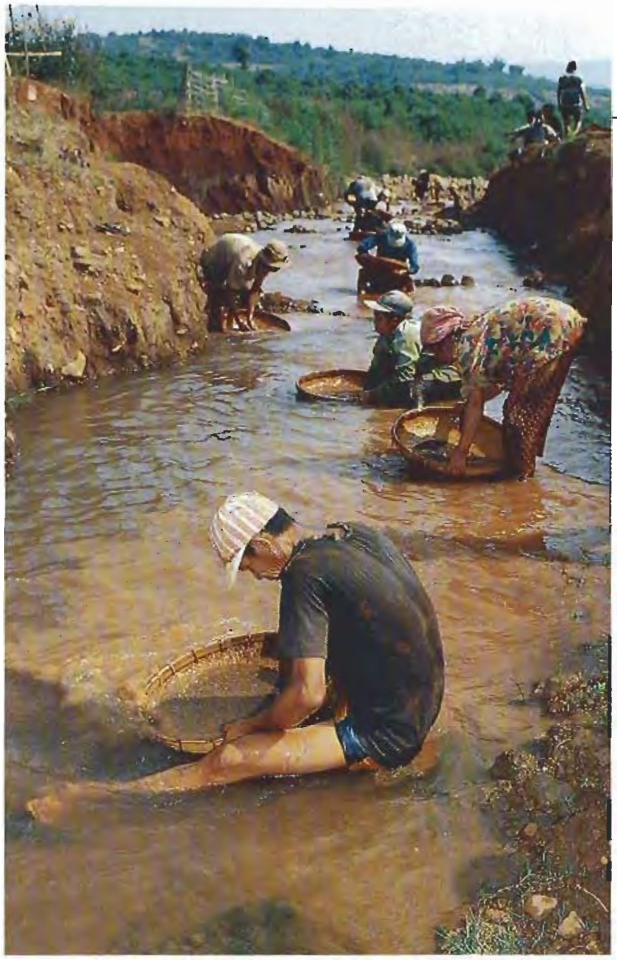


Figure 16. Soil and gravels, recovered from pits like that shown in figure 15, are washed for sapphires in a local stream. Photo by Robert C. Kammerling.

The Tranomano Precambrian crystalline schists are embedded between the Anosyenne chain and the Androy volcanics in southern Madagascar. The Tranomano units form the central part of a peneplain; these crystalline schists were subjected to strong (granulite facies) metamorphism, and consist of pyroxenites, garnet gneisses, and pyroxene gneisses. These rocks were folded and a granitic mass intruded, from which pegmatite dikes emanated further into the pyroxenites. Sapphires formed locally in the reaction zones between the pegmatite dikes and the pyroxenite; these deposits take the form of nests and pockets. The sapphire crystals are usually small (5–15 mm across) and are light-to-dark blue in color (figure 18). Crystal shapes observed vary from columnar to pyramidal and distorted tabular shapes; crystal faces identified so far include *c*, *a*, *r*, *n*, *w*, *z*, and a rare scalenohedral form. These faces not only define the surface morphology of the crystals, but they also are frequently encountered within the crystals, where they form growth and color bands. Electron microprobe analyses revealed significant variations in the concentrations of chromophore elements Fe (0.15–0.25 wt.% Fe as Fe_2O_3) and Ti (0.05–0.15 wt.% Ti as TiO_2). The absorption spectrum is similar to that of Sri Lankan and Burmese sapphires, with a weak-to-moderate Fe^{3+} absorption at 450 nm.

Mineral species identified in the (very calcite-rich) associated parent rock include: calcite, feldspars, quartz, diopside, mica, anatase, spinel, apatite, wollastonite, and a mixture of clay minerals. Inclusions found in the sapphires are: apatite, calcite, spinel, diaspore, CO_2, and rutile. These were identified by Raman spectroscopy and SEM-EDS. Rutile needles were not present or were very small. Turbid areas in the crystals may be composed of fine, submicroscopic TiO_2 precipitates. Because many crystals have sectored color zoning and/or turbid areas, sapphires from this locality will probably need heat treatment to be marketable.

Scapolites from new discoveries in Sri Lanka. The gemological properties of scapolites from Sri Lanka were discussed by Pieter C. Zwaan, of Leiden, the Netherlands, and E. Gamini Zoysa, of Mount Lavinia, Sri Lanka. These yellow to near-colorless stones came from eluvial and alluvial deposits near Pohorabawa, a small village in the Eheliyagoda area, and in the Embilipitiya area.

The Eheliyagoda specimens had mean refractive indices of 1.542 (extraordinary ray) and 1.560 (ordinary ray), birefringence of 0.018, specific gravity of 2.632, and composition of $Marialite_{67.5}Meionite_{32.5}$. There are two groups of Embilipitiya scapolites: one with gem properties similar to those from the Ehilayagoda area, and the other with refractive indices of 1.550 (extraordinary ray) and 1.578 (ordinary ray), a birefringence of 0.028, a specific gravity of 2.693, and a composition of $Marialite_{40.5}Meionite_{59.5}$. This second group of scapolites also may contain needle-like inclusions of pyrrhotite.

Scapolites can be distinguished from other yellow Sri Lankan gemstones with similar properties (such as citrine and various feldspars) by their strong orange-yellow to

Figure 17. This handful of sapphire rough, seen at a mining site near Ban Houay Xai, appears to be typical of the sapphires being produced in the area. Photo by Robert C. Kammerling.

"canary" yellow fluorescence to long-wave UV radiation and their much stronger birefringence.

With regard to gemological properties, Eheliyagoda scapolites have much in common with those from Tanzania, whereas most Embilipitiya scapolites are very similar to scapolites from Madagascar. Among the scapolites from other localities that were available for identification was a 2.06 ct violet stone from Pakistan, which had the lowest numerical values for physical properties and the lowest meionite content (composition Marialite$_{92.4}$ Meionite$_{7.6}$) ever observed in the Netherlands Gemmological Laboratory.

Tanzanites and other zoisites from Merelani, Tanzania. Why do so many colors of zoisite come from such a small area in Tanzania? Why does some zoisite exhibit a color change after heat treatment, while some does not? To answer these questions, Contributing Editor Henry Hänni (aided by Daniel Traber and Dr. N. Barot), analyzed 42 zoisite crystals and chips both chemically and spectroscopically.

Chemical investigations were carried out by microprobe, with special attention given to the chromophores Fe, Ti, Cr, and V. Quantitative results showed low aluminum contents (compared to the ideal zoisite formula). This suggests substitution of the chromophores for Al, either as a simple substitution or coupled with some other substitution. Brown and blue samples typically had a V_2O_3/Cr_2O_3 ratio greater than two; this ratio was less than two for green samples. Light blue crystals with elevated TiO_2 contents showed only a weak response to heat treatment, despite their vanadium content. Manganese and iron were found in very low concentrations only; hence, the authors did not consider these elements to be relevant with regard to the colors of the Merelani zoisites. A green zoisite from Pakistan and a pink zoisite (purchased in India) were tested for comparison purposes, and were found to have significant iron contents.

Violet zoisites owe their color to V^{3+}. The addition of a little Cr^{3+} results in a purer blue. The transition from brown to blue is caused by destruction of the 450 nm absorption band on heat treatment. (Both the brown pleochroic color and the 450 nm absorption band are polarized parallel to the c-axis.) Samples with elevated Ti contents (which are usually light blue) showed weak reactions to heat and kept the 450 nm feature to a certain extent. The authors speculate that the color transition mechanism (with heat treatment) is: $Ti^{3+} + V^{4+}$ converting to $Ti^{4+} + V^{3+}$ as titanium is oxidized with heating; they hope that further investigation will confirm this hypothesis. Finally, they noted that infrared spectroscopy revealed no features that would be diagnostic for heat treatment in zoisite.

SYNTHETICS AND SIMULANTS

Russian flux-grown synthetic alexandrites. One of the contributing editors, Dr. Karl Schmetzer, examined about 200 crystals of flux-grown synthetic alexandrite obtained from Novosibirsk and Bangkok. About 90% of the crystals showed cyclic twinning; the balance were untwinned single crystals. Dr. Schmetzer identified as external crystal faces (dominant faces underlined here for emphasis) pinacoids *a* (100), *b* (010), and *c* (001); rhombic prisms *s* (120), *k* (021), *x* (101), and *m* (110); and one rhombic dipyramid *o* (111). X-ray fluorescence spectroscopy revealed minor-to-trace amounts of Cr, Fe, V (in some samples), Ge, Bi, and Mo. Cr, V, and Fe are chromophores. Bi and Mo were already known to be components of the flux material used in Russia for the growth of synthetic alexandrites, but the presence of germanium, sometimes greater than 1 wt.% GeO_2, was surprising.

Figure 18. These sapphire crystals from southern Madagascar range from light to dark blue. The largest is about 15 mm long. Photo courtesy of Henry A. Hänni, SSEF.

The crystals showed growth zoning parallel to the four dominant *a*, *x*, *k*, and *o* faces (figure 19), which was also seen as zoning of Cr, Fe, Ge, and V (again, in some samples) with the electron microprobe. About 10% of the samples revealed an intense red (in incandescent light) core, with a lighter red rim, and a rounded, still more intense red boundary between the two. Chromium content ranged up to 4 wt.% Cr_2O_3 in the boundary area, which indicates a two-stage growth process for some of the synthetic alexandrites.

GGG as a corundum fake. Over the past few years, reports have appeared here and elsewhere about the danger of inadvertently purchasing synthetic rubies that have been fashioned to resemble waterworn natural rubies from Vietnam (see, for example, Winter 1991 Gem News, p. 260). We have also heard of an imitation Mong Hsu ruby that is produced by inserting a blue, wax-like substance into a cavity in synthetic ruby; the wax superficially resembles the blue central zone typical of material from that locality.

While in Taunggyi, Editor R. C. Kammerling learned of another deception being used on local jewelers: Large pieces of purple GGG are fashioned to resemble corundum crystals and misrepresented as material from a "new" deposit. One such imitation, shown by U. Tin Hlaing (who had identified the specimen as GGG), had a rough-ground surface with fairly convincing parallel striations on the

Figure 19. This Russian flux-grown synthetic alexandrite shows a characteristic growth pattern consisting of two a (100) pinacoids (left and right) and two o (111) rhombic dipyramids (top). Photomicrograph (immersion, incandescent light) courtesy of Karl Schmetzer; magnified 40×.

crystal "faces" (figure 20). Because of the rough surfaces, it was difficult to examine the interior of the piece, even with strong transmitted light. However, its deep purple color was very evident. Unwary jewelers, seeing this transmitted purple color, might mistake it for a mixing of colors from the red periphery and blue core of a Mong Hsu-like crystal.

INSTRUMENTATION

The lapidary as a gemological resource. Michael Gray, of Graystone Enterprises, Missoula, Montana, pointed out that lapidaries—the people who fashion gem rough into cut stones—can be an invaluable source of gemological information, especially with regard to new materials, and locality and treatment information. For instance, the fact that benitoite was too soft to be sapphire provided the first clue that it was a new mineral. In Mr. Gray's experience, heat-treated corundums do not respond to cutting and polishing in the same way that untreated stones do, and bicolored tourmalines from different localities behave differently during faceting.

Nuclear microscopy of rubies. Mr. Tay Thye Sun, of the Far East Gemological Laboratory, Singapore, described the use of a nuclear microscope to determine trace-element contents in rubies. In this research, carried out in collaboration with the National University of Singapore Nuclear Microscopy Group, a focused beam of high-energy protons is raster-scanned across the sample's surface; X-rays (Particle Induced X-ray Emission, or PIXE) and backscattered protons (Backscattering Spectrometry, or BS) are collected from regions as small as 1 micron. Depths of around 30 microns are probed. The method allows the determination of trace-element concentrations at the 1 ppm level from homogeneous regions near the stone's surface, where no inclusions or surface contaminations are present.

In addition to the six rough samples from Mong Hsu and four cut stones from Thailand that had been studied in detail, Dr. Tay presented preliminary results for 105 rubies from various Myanmar localities. The Thai stones had higher Fe contents than the Mong Hsu rubies, but the Mong Hsu stones had more V and Ti. The dark Mong Hsu core regions were high in Cr and Ti.

Raman spectrometers. Interest in Raman spectroscopy as a gemological technique continues to grow because of its usefulness as a nondestructive technique to identify inclusions in gemstones. Dr. Prof. Bernard Lasnier, of the Gemmology Laboratory at the University from Nantes, France, reported that the technology of gemological Raman spectrometers continues to improve; Han A. Talay of the University of Nantes has developed a new unit that is portable (it weighs 15 kg) and can also be used for colorimetric measurements.

Figure 20. This rough "crystal" of purple GGG was misrepresented to a jeweler in Taunggyi, Myanmar, as a corundum gem from a new locality. Photo by Robert C. Kammerling.

Dr. Jamie Nelson, of London, England, provided a very lucid description of how the Raman effect works, and reported that he is developing a catalog of Raman spectra of gemstones and their inclusions, which currently contains 150 entries. (For an existing catalog of 80 Raman spectra of gems and their inclusions, see the 1992 special Raman spectroscopy issue of *Revue de Gemmologie* [abstracted by E. Fritsch in the Fall 1993 *Gems & Gemology*, p. 224]. A more extensive catalog—with more than 600 mineralogical standards—is currently in press in Nantes.) Garry du Toit, of the Asian Institute of Gemological Sciences in Bangkok, showed several Raman spectra of inclusions in gems, including calcite in a Burma ruby that had been heat treated to an extreme degree and the emerald fillers cedarwood oil, Opticon, and a "different type of resin" used in Bangkok, which is activated by UV radiation.

In a panel discussion following these presentations, some limitations of the Raman technique were pointed out. Inclusions must be fairly close to the surface of the gem being studied; and, in highly fluorescent stones, luminescence can totally swamp the Raman signal (unless multiple lasers, or other methodological changes, are used).

Brewster angle refractometer. Dr. Roger Harding, of the Gemmological Association and Gem Testing Laboratory of Great Britain, described an instrument that works by measuring the angle at which the light reflecting off the surface of a gemstone is most highly polarized (the Brewster angle). A laser serves as the high-intensity monochromatic light source; however, as the lasers employed to date emit light in the red end of the spectrum (632.8 or 670 nm), and not at the 589 nm sodium D line, the measurements must be converted (that is, the dispersion must be known) in order to compare results with conventional refractometers. Thus, a table of Brewster angles (at 670 nm) is more convenient for recording and comparing data. With this instrument, the Brewster angles of diamond and CZ can be distinguished, and no optical coupling fluid (such as R.I. liquid) is needed.

MISCELLANEOUS

Gems in ancient jewelry. Jewelry from a 4th century B.C. sepulcher was the topic of a talk given by Jean-Paul Poirot, of the Service Public du Controle des Diamants, Perles Fines et Pierres Précieuses, Paris. The sepulcher was of the Achemenid period in Susa (modern Iran).

The gems in three beaded necklaces, two buttons, two ear pendants, one torque, and two bracelets were identified. Drilled beads from one single- and one four-strand necklace included: quartz (rock crystal, amethyst, smoky quartz); cryptocrystalline quartz (including carnelian, sardonyx, onyx, brown banded agate, red and yellow jasper, and other chalcedony) and siliceous rocks; hematite and ferruginous rock; feldspar porphyries with black body colors; and limestone, mother-of-pearl, amazonite, turquoise, malachite, serpentine, lapis lazuli, gold beads, and "artificial products" (sintered glassy frits with bluish white body colors).

The necklace with cloisonné beads, and all the other pieces, contained cloisonné inset with lapis lazuli, carnelian, agate, and turquoise. In one piece, amazonite was used to imitate turquoise in an inconspicuous place. All the pieces showed signs of wear and weathering, such as stones missing from the enamel work and the alteration of some lapis lazuli caused by pyrite decomposition. They also showed that culture's appreciation of turquoise and lapis lazuli, and the influence of neighboring civilizations.

Figure 21. Gems & Gemology *Editor Alice Keller accepts the trophy for best scientific/educational feature article from ASAE President R. William Taylor.*

ANNOUNCEMENTS

***Gems & Gemology* wins again.** For the fourth consecutive year, *Gems & Gemology* won an award in the prestigious American Society of Association Executives (ASAE) Gold Circle competition. For 1995, the journal received a first-place trophy in the category "Feature Writing, Scientific/Educational" for the article "An Update on Filled Diamonds: Identification and Durability," by R. C. Kammerling, S. F. McClure, M. L. Johnson, J. I. Koivula, T. M. Moses, E. Fritsch, and J. E. Shigley (which appeared in the Fall 1994 issue and was the recipient of *Gems & Gemology's* own "Most Valuable Article" award). *Gems & Gemology* also placed second overall in the "Journals" category. Editor Alice Keller traveled to Chicago in early December to receive the trophy on behalf of the journal (figure 21).

BOOK Reviews

SUSAN B. JOHNSON AND
JANA E. MIYAHIRA, EDITORS

PHOTO MASTERS FOR DIAMOND GRADING

*By Gary A. Roskin, 94 pp., illus., publ. by Gemworld International, Northbrook, IL, 1994. US$75.00**

By the title alone, I anticipated *Photo Masters for Diamond Grading* to be a practical combination of E. Gübelin and J. I. Koivula's *Photoatlas of Inclusions in Gemstones* and GIA GEM Instrument's MicroVision 2000. After reading *Photo Masters*, I realized that it is not intended to be a "master" for grading in the same sense that "master color" comparison diamonds are used for color grading. The value of this book is as a reference guide for the trade, mainly for retailers and rusty diamond graders. I used it with a customer in my store to clarify the difference between a VVS_2 feather and a VS_1 feather. It provided the example we needed without my actually looking through dozens of loose diamonds.

This glossy hardcover book has more than 200 color photomicrographs of diamonds representing all clarity grades and other grading characteristics. It is well organized, with a concise table of contents, enjoyable introduction, and a good history of the evolution of diamond grading. For the most part, the caption to each photomicrograph gives the diamond's carat weight, clarity grade, level of magnification, and the grading laboratory, if any. However, not all captions give all of this information, and this book should continue to be updated.

The main grading issue Roskin deals with is clarity. Although this book will not thrust you into the circle of the professional diamond grader, as the title and preface might imply, it does offer a second opinion to help the reader strive for "consistency in an evolving grading system." Nevertheless, more pages should have been devoted to the clarity issue. I also felt that the chapters on Reflectors, Fancy Shapes, Fancy Colors, Large Diamonds, and Recutting were far too short.

Another concern is visual perception as it relates to the use of photomicrographs. A common magnification level (10×) for all diamonds illustrated would have provided a much more realistic comparison within any one clarity grade. As presented, one can look at a dozen different VS_2 inclusions, but, because each is shown at a different magnification, it is impossible to compare them.

The last chapter, on Laboratory Comparisons, seems to have one aim: to show SI_3 clarity grades where they had not been shown before. Even so, the discussion is incomplete and leaves the issue of differences between laboratories unresolved (e.g., the GIA Gem Trade Laboratory does not use this grade). In this reviewer's opinion, it is inappropriate as a concluding chapter to a book that purports to be striving for *consistency* in diamond grading.

Nevertheless, this book achieves its stated purpose of helping to reduce inconsistencies in grading, and it is a valuable tool for the appraiser, wholesaler, and retailer. As a retailer and former diamond grader, I would give *Photo Masters for Diamond Grading* an SI_2 . . . Salable but Incomplete, **too.**

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A SPARKLING AGE, 17TH-CENTURY DIAMOND JEWELLERY

*223 pp., illus., publ. by the Diamantmuseum, Antwerp, Belgium, 1993, US$65.00**

This bilingual (Flemish/English) catalog of an exhibition held at the Province Diamond Museum in Antwerp June 11–October 3, 1993, capably demonstrates the splendor of diamond jewelry in the 17th century—aptly called "A Sparkling Age." This soft-cover book offers rich insights into both the development of diamond cuts and changing tastes in jewelry during this era.

Four articles provide background information for the exhibit. In the mid-1600s, the use of table-cut diamonds and the introduction of rose-cut diamonds helped move jewelry design away from elaborate precious-metal and enamel work, reducing their role to that of decorative motif. A scant 40 years later, Parisians demanded more facets on the sides of table-cut diamonds—the first recorded attempt at the brilliant cut. Supporting this historical footnote, Jan Walgrave's article on "Diamond Cuts in the 17th Century" definitively states that "The brilliant [cut diamond] exists already before 1700 but only some decades later completely supersedes the table diamond." Jan Walgrave also provides articles on "Tendencies in 17th-Century Jewellery" and a description of the miniature case of King Louis XIV of France, given by that monarch to a Dutch envoy in 1683.

Diana Scarisbrick, noted British jewelry historian, writes an absorbing 13-page article, "17th-Century Diamond Jewellery and the Ornamental Print." She relies on the ornamental prints that were published for jewelers and their clients to trace the history of jewelry from the end of the 16th century to the reign of Louis XIV at Versailles.

In the actual catalog portion of the book, a rich narrative accompanies each of the crisply illustrated 107 jewelry items. Many of the illustrations show details of the counter engraving or counter enameling prevalent at that time. In a number of instances, a line drawing of the faceted diamond accompanies the photo and text.

Although this book lacks a table of contents, glossary, or index, it is relatively easy to follow along chronologically. The reader can visually track trends in jewelry design and diamond cuts as they emerge and are refined during this fascinating era. For those interested in specific items or types of jewelry, though, browsing would be a problem.

GAIL BRETT LEVINE
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GEMOLOGICAL ABSTRACTS

C. W. FRYER, EDITOR

COLORED STONES AND ORGANIC MATERIALS

Building a new image for Australian pearls. R. Shor, *Jewelers Circular-Keystone*, Vol. 166, No. 10, October 1995, pp. 72–74, 76.

Australia's 16 pearl farmers have decided to aggressively market and advertise their South Seas pearls themselves. Going beyond the traditional small group of Japanese buyers, the farmers want to sell to distributors worldwide, reduce trading in the yen, and create a separate, more prestigious identity for their product.

This article reviews the history of the over-100-year-old Australian pearling industry and its connection with the Japanese. Shor reports that in recent years, innovations by the Australian farmers have lowered mollusk mortality rates and increased production.

Producers think that the U.S. will be the next big market for their product. Although necklaces of Australian pearls have sold at auction for as much as US$500,000, farmers hope that simpler jewelry will bring their products more into the range of mainstream affordability. At one retail store in Sydney, less costly designer jewelry—using one or two pearls—starts at $300 (but averages between $2,000–$8,000); the items are produced by local Sydney designers, as well as by international design houses such as Carrera y Carrera, Buccellati, and Leo de Vroomen of London.

Australian quotas limit the harvest of "wild" pearl oysters to 537,000 oysters annually (16,000–100,000 per company). Almost all are harvested off 80 Mile Beach, west of Broome. However, Australia will allow each company to add 20,000 hatchery-grown oysters to its operating stock. Hatchery pearls are described as "more uniform and much less exciting." *JEC*

The definition of a mineral. E. H. Nickel, *Canadian Mineralogist*, Vol. 33, 1995, pp. 689–690.

The International Mineralogical Association (IMA) Commission on New Minerals and Mineral Names (CNMMN) decides whether a newly described substance is a mineral (and, if it is, whether a proposed name is acceptable), as well as which existing mineral species designations are no longer acceptable and should be discarded.

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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Their decisions can have implications for gemology, especially on the criteria for natural as compared to "man-made" materials. In this article, Dr. Nickel, vice-chairman of the CNMMN, explains the current definition used to determine whether a substance is a mineral.

"In general terms, a mineral is an element or chemical compound that is normally crystalline and that has been formed as a result of geological processes." By this definition, amorphous substances (such as opal) usually are not considered minerals, although there are a few exceptions (georgeite, calciouranoite). Metamict materials (that is, materials made amorphous by large amounts of radiation damage) may be accepted as minerals if there is evidence that the material was crystalline before radiation damage. Virtually all liquids are not minerals (the exception is mercury). However, when solidified (such as ice), they may be minerals, even if they are not stable at room temperature or ambient pressure. Extraterrestrial substances (such as the lunar mineral tranquillityite) can be minerals. Geologic processes are not limited to those on Earth!

For gemologists, the debatable materials are biogenic (formed by living creatures), anthropogenic (formed by humans), or anthropogenic with later geologic modifications. As examples in the first category, a natural substance (such as a pearl) that forms in or as the body of a living creature is typically not a mineral; however, the material that results when some natural substances have been affected by geologic processes (e.g., struvite in bat guano, anapaite in fossil mollusk shells) may be a mineral.

No anthropogenic substance is accepted as a mineral, although it may be a "synthetic equivalent." In the past, some anthropogenic materials that had been modified by geologic processes were accepted as minerals. These include compounds found in the silver-mining slags of Laurium, Greece, which formed as the slag sat in seawater for centuries, and some new chemical compounds formed in mine fires. The CNMMN will no longer accept such substances as new minerals. However, materials formed by weathering (or other geologic processes) of rocks may be new minerals, even if human activity set the processes in motion—provided that said activity was *not* done expressly to create new minerals. Thus, if you made a road cut in which a new mineral later formed by weathering, that mineral would probably be acceptable to the commission. However, if you piled up 100 miscellaneous meteorites, stuck a lightning rod in the pile, and prayed for a thunder storm, your new products would probably not be called new minerals. *MLJ*

Flat pearls from biofabrication of organized composites on inorganic substrates. M. Fritz, A. M. Belcher, M. Radmacher, D. A. Walters, P. K. Hansma, G. D. Stucky, D. E. Morse, and S. Mann, *Nature,* September 1, 1994, pp. 49–51.

Materials scientists have discovered that organic processes can be very effective in growing unusual composite materials. One common example is the growth of organic-templated aragonite, also known as the nacreous layers in pearls. In this article, the authors show that "flat pearls"—iridescent regions of oriented columns of flat aragonite plates—can be grown on disks of glass, mica, and molybdenite (MoS_2) inserted between the mantle and shell of red abalones, *Haliotis rufescens.* The development of pearly layers appears governed by processes in the abalone mantle cells that are triggered by the presence of inorganic material between the mantle and the shell.

Abalones were chosen for these experiments because they grow nacreous material faster (about 26 times) than bivalves, and they lack the complicated bivalve "pearl sac." Eighteen-millimeter-diameter disks of glass, mica, and molybdenite were inserted between the mantle and the shell in living red abalones, and then removed 14 days later; nacreous layers grew on all three types of disks. To better understand the depositional process, the authors repeated the experiments, withdrawing the disks at shorter intervals. They found the following sequence: (1) The first material to be deposited was calcite, which grew in 100 μ intergrown crystalline blocks (day five); (2) the first aragonite nucleated in discrete sites on this calcite surface after seven days; and (3) highly ordered columnar aggregates grew from these nuclei and covered the disk surface (between days seven and 14, about 200 aragonite layers formed).

The authors isolated some of the proteins responsible for pearl growth, and concluded that the timing of the growth of inorganic materials resembles that of natural shell material. *MLJ*

In Hong Kong, record prices for jade. *National Jeweler,* July 16, 1995, p. 26

Two world-record prices for jade and the appearance of new major buyers marked Christie's early-May auctions in Hong Kong. The May 1, jadeite-only auction brought $7.8 million, almost double the previous year's figure. The sale's highlight was a magnificent jadeite bangle that set a world-record price of $1.5 million, far more than the last auction record of $900,000. A pair of jadeite saddle rings went for double their estimate—$460,000—another world record. The May 2 session took in $3.8 million, up 140% over the same sale a year earlier. A 7.39 ct emerald fetched $182,000, and a 6.12 ct Burmese ruby sold for $174,000. *MD*

A note on red beryl. R. R. Harding, *Journal of Gemmology,* Vol. 24, No. 8, pp. 581–583.

This brief note summarizes the characteristics of an unusually large (4.66 ct) faceted specimen of this gem material. The characteristics were consistent with those previously reported for red beryl from Utah, except that the iron and manganese contents for this sample were higher and, thus, related absorption features were observed. (Readers should note that the absorption spectrum illustrated is from a diffraction-grating, not prism, spectroscope.)

Mineral inclusions of bixbyite and columbite were identified; other, unidentified, mineral inclusions were also observed. The results of SEM-EDS analyses for the beryl and its mineral inclusions are provided in a table. *CMS*

Other gemstones. C. R. Cavey, *Metals & Minerals Annual Review 1995*, 1995, p. 31.

Although 1994 mining production increased in many areas, the worldwide recession lowered demand for gemstones. The gem market also became riskier, with the wide distribution of synthetic gems, especially Russian and Japanese synthetic amethyst and citrine. The gem-cutting market in India remained stable, and production activities in Thailand increasingly centered on the heat treatment of corundum gems.

General demand for ruby was not strong in 1994, and most of the new production was heat treated. Myanmar's ruby production, primarily heat-treated [Mong Hsu] stones, remained stable for the year. Sri Lanka's production benefitted from a better political climate and from new mining and marketing efforts; again, most stones were heat treated. Rubies from Vietnam were readily available; however, parcels of these stones have been salted with imitation rough made from flame-fusion and flux synthetic corundum. A few natural rubies came from Russia, and low-grade material was available from Norway. There was little evidence of mining in the region around the Tajikistan-Afghanistan border.

Sri Lanka produced "large quantities" of sapphires and is adding more gem-cutting and polishing centers; local interest in heat treatment also expanded, in response to a growing reluctance to send stones to Thailand for processing. Thailand continued to produce medium- and low-quality (with small amounts of good-quality) sapphires. In addition, large amounts of Sri Lankan, Australian, Nigerian, and Chinese stones are imported into Thailand for heat treatment. Nigeria continued to mine dark blue sapphires, and many colors of corundum came from the Umba River Valley in Tanzania. Sapphire mining continued in Montana, a few stones were found in Madagascar, and a dark blue/brown sapphire of more than 1,000 carats was rumored to have been found in Yemen.

Emerald production increased in Colombia, with some gems weighing more than 50 ct; however, virtually all the stones were subjected to "resin in-filling." Brazil's emerald ouput remained stable. Production from Africa—from Sandawana and other sites in Zimbabwe, Zambia, Mozambique, Nigeria, and South Africa—was erratic in 1994. There was an unconfirmed report of a "fine emerald" found in Kenya. Recent production was also available from Russia, with some cut gems reported in sizes as large as 50 ct.

Emerald prices remained low in 1994; prices for aquamarines fell after a quantity of fine material was discovered in Madagascar. Other aquamarine-producing countries included Brazil, Nigeria, Zambia, Zimbabwe, Pakistan, and Sri Lanka.

Paraíba tourmalines continued to be popular, although similarly colored heat-treated apatite proved to be a plentiful, cheap alternative. Irradiated and heat-treated blue topaz was also readily available. Finally, Russia produced one of the oddest synthetic gems on the market—synthetic malachite. *MLJ*

Rare natural pink clinozoisite (in Japanese). Y. Kitawaki, *Gemmology*, Vol. 25, No. 301, October 1994, p. 11.

The author reports on a transparent pink stone that was brought to his laboratory and subsequently identified as clinozoisite. The article includes a photograph of the stone face-up and a description of the stone's various gemological properties. The cause of the unusual color could not be determined; however, the author suspects that a minute amount of manganese might have been responsible.

HN

DIAMONDS

Ashton joins KWG Resources and Spider Resources in venture. *Diamond Industry Week*, Vol. 2, No. 29, July 31, 1995, pp. 7–8.

Most news about diamond exploration in Canada has concerned the "Corridor of Hope" in the Northwest Territories. However, KWG Resources and Spider Resources have discovered diamonds in the James Bay Lowlands area of Northern Ontario. Ashton Mining of Canada has joined them for the testing phase of a new property, Kyle No. 3. As of July 31, 1995, 96 microdiamonds (less than 0.5 mm in maximum dimension) and five macrodiamonds had been recovered from 454 kg of kimberlite drill core. Most garnets from the discovery hole plot "well within" the G10 range favorable for diamonds, and chromite compositions appear favorable, too.

Ashton is also evaluating diamondiferous properties in the Northwest Territories, as well as near Lake Superior in the United States. *MLJ*

Botswana backs renewals with the CSO. A. Katz, *Mazal U'Bracha*, No. 67, May 1995, pp. 96–100.

Botswana has become Africa's economic success story because of its diamond and other mineral resources. Mr. Archibald Mogwe, Botswana's Minister of Mineral Resources and Water Affairs, believes that his country is a wealthy, stable democracy because it has maintained control over its mineral-rich land. At a recent diamond conference in Perth, Australia, Mr. Mogwe gave De Beers high marks for unearthing the resources by which "Botswana lives or dies." Since the mid-1960s, Botswana and the CSO have been equal partners in that country's diamond mining and marketing, as well as resultant revenues. To date, only De Beers has found viable diamond deposits in Botswana.

Botswana's five-year contract with De Beers expires at the end of 1995, but both parties are pleased with the arrangement and intend to renew. Mr. Mogwe saw no reason to follow Russia's lead in threatening to break with the CSO, preferring De Beers's marketing expertise to experimenting "with unknown marketing structures." *AC*

Crystal forms and surface textures of alluvial diamonds from the western region of the Central African Republic. C. Censier and J. Tourenq, *Mineralium Deposita*, Vol. 30, No. 314, 1995, pp. 314–322.

Samples of the most common crystal forms of alluvial diamonds from the western region of the Central African Republic were examined by scanning electron microscope to determine their geologic history. The marks observed were related to two distinct periods of transport: magmatic and hydraulic.

The diamonds underwent significant magmatic corrosion during their ascent from the upper mantle. Evidence for this included the fact that there were more rhombododecahedral than octahedral forms, the frequent occurrence on the crystal faces of pyramidal depressions with triangular (111) or square (100) bases, and the presence of V-shaped (111) or stepped figures on the faces around the ternary axes. Some impact marks probably occurred during the explosive episode of kimberlite extrusion.

Other impact marks, the marks of general wear, and the high proportion of gem-quality diamonds indicated that these crystals had endured both lengthy transport and a long geologic history after erosion from the kimberlite. This suggests that the kimberlite is some distance from the sandstone formation. The diamonds were stored in Albian-Maastrichtian rocks before they became concentrated in recent alluvium. *RAH*

Development: De Beers retreats . . . *Mining Journal, London,* June 23, 1995, p. 462.

In November 1993, De Beers agreed to participate in the expansion of gold concessions held by Ghana Consolidated Diamonds in Akwatia and the neighboring Birim River. Over the next 14 months, these deposits produced 387,000 carats of industrial and near-gem diamonds. However, bulk sampling of the remaining "meander belt" deposits of the center channel of the Birim River has revealed lower-than-anticipated economic potential. Consequently, De Beers decided to withdraw from the project. *MLJ*

Virtual diamonds by fax and on the Internet. *Diamond Registry,* Vol. 27, No. 9, 1995, p. 2.

Potential buyers are warned to be *very* suspicious of unsolicited e-mailed or faxed offers for large quantities of rough diamonds at discounted prices. When an offer seems too good to be true, it probably is: "Virtual diamonds" may be a ruse to find out a would-be buyer's bank account number. The offer illustrated here was for one million carats (!) of rough diamonds in sizes of one to 20 carats, to be delivered at a rate of 8,000 carats per month. When such sellers are asked for a sample shipment of a few hundred carats before any funds are committed, though, they become "insulted" and cut the conversation short. The actual source of these offers, which appear to originate in the U.S., South America, Europe, or Africa, has not been determined. However, as the newsletter warns: "Real diamonds come in small packages and real miners show their wares before a deal is consummated." *MLJ*

World rough production holds at 1993 levels. *New York Diamonds,* No. 29, March 1995, pp. 60–61.

In 1994, the world's diamond mines produced 57 million carats (Mct) of gem and near-gem diamonds, about the same as 1993, according to statistics released by the U.S. Bureau of Mines. The only leading producer with any significant change was Zaire, where output fell 5.2% (to 9 Mct) because of continuing government instability. Australia, the largest producer of gem diamonds by weight, yielded 19 Mct; Botswana, the largest producer by value, totaled 12 Mct.

Russia mined 8 Mct, which was equal to its 1993 production but down 11% from 1992—a drop probably caused by the maturity of the major Russian mines. Russia is moving closer to production, but still in the testing phase, at six major kimberlite pipes at Archangelsk.

South Africa produced 4.3 Mct in 1994. Namibia's output was 1.1 Mct; mine ownership there was partially nationalized in November 1994, with the new holding company, Namdeb, owned equally by the Namibian government and De Beers. Official production in Angola continued at the 0.5 Mct level to which it had fallen the preceding year (from 0.8 Mct in 1992); however, these figures do not include illegal mining, which is believed to be significant.

Testing of diamond deposits continued in Arkansas (Crater of Diamonds in Murfreesboro) and the Colorado-Wyoming border. Prospecting was also ongoing in Alaska, Minnesota, and Wisconsin, but the United States—like Canada—had no commercial diamond production in 1994.

World diamond reserves are estimated at 300 Mct (mostly in Africa, Russia, and Western Australia). Fifty million carats of industrial diamonds were mined in 1994, with 23 Mct of these from Australia.

The U.S. Bureau of Mines extrapolated all current production figures in this report from known production for the year's first three quarters. They reflect only official figures released by the governments involved. *MLJ*

GEM LOCALITIES

Benitoite and joaquinite in Arkansas. H. Barwood, *Mineral News,* Vol. 11, No. 5, May 1995, pp. 2, 5.

The rare gem mineral benitoite, $BaTiSi_3O_9$, is found in facet-grade pieces at the Gem Mine in San Benito County, California. Recently, it was discovered at the Diamond Jo quarry in Magnet Cove, Arkansas. Three specimens have been found of clear "sky-blue" anhedral (that is, having no external crystal faces) grains embedded in pectolite. X-ray powder diffraction analysis confirmed that this strongly fluorescent material was benitoite; the dimensions of the grains were not given. There are unconfirmed reports of benitoite from Texas *[Editor's note: See related abstract in this issue, "The reported benitoite . . ."]* and Belgium, but this is only the second confirmed locality for benitoite. Rare-earth-poor joaquinite is also found at the Diamond Jo quarry, and is possibly a new species in the joaquinite group. *MLJ*

Burmese sapphire giants. R. W. Hughes and U. H. Win, *Journal of Gemmology,* Vol. 24, No. 8, pp. 551–561.

Some of the world's finest blue sapphires have come from the Mogok region of Myanmar. Once denigrated by gem enthusiasts as usually being too dark, Mogok sapphires are recognized today as representing the full range of blues. Some exceed 100 ct when cut.

For the most part, the blue sapphires occur in association with the rubies for which Mogok is best known, but a few localities yield primarily blue sapphires. The authors provide a map of the sapphire-producing localities near Mogok.

Famous large blue sapphires from Mogok include the 958 ct rough "Gem of the Jungle," which was found in 1929. It was cut into nine stones, the largest of which weighed 66.53 ct. A 502 ct crystal (illustrated in the article) of fine blue color and slightly silky clarity was found in 1994. Two tables list exceptional specimens of gem and nongem sapphire from sources worldwide. Among the nongem specimens is a 63,000 ct crystal from Mogok that was unearthed around 1967. *CMS*

Cat's-eye and asteriated gemstones from East Africa. N. R. Barot, G. Grazianai, E. Gübelin, and M. Rettighieri, *Journal of Gemmology*, Vol. 24, No. 8, pp. 569–580.

The authors describe the characteristics of 19 assorted chatoyant or asteriated gemstones from East Africa, which has become a significant producer of such stones. Their samples include alexandrite, various garnets, apatite, aquamarine, greenish yellow beryl, kyanite, kornerupine, ruby, sapphire, scapolite, tourmaline, and zoisite. Photomicrographs illustrate the various oriented microscopic features that generate the phenomena, including rutile needles, tubes, lamellar structures, healing fissures, and cleavage laths. Tables summarize the basic properties of the samples and the inclusions that were identified in them. *CMS*

Diamond mining in Bingara, part 1. J. Hume, *Australian Gold Gem & Treasure*, Vol. 10, No. 8, August 1995, pp. 21–22, 52, 54.

The first report of diamonds in New South Wales, Australia, was by E. H. Hargraves, who found what were claimed to be diamonds at Reedy Creek, near Bathurst, in July 1851. Three months later, a diamond from the Turon River was shown to geologic surveyor S. Stuchbury, and six diamonds were found in the tributaries of the Macquarie River in 1860. The first commercially important diamond find was made in 1867 at Two Mile Flat, near the Cudgegong River, west of Gulong. These alluvial diamonds were found in Tertiary river gravels. Between 1867 and 1870, 1,765 diamonds (up to 1.25 ct) were recovered from the Cudgegong field by the Australian Diamond Mines Company.

Operations ceased in 1870, when a major flood destroyed nearly all the recovery machinery. In 1872, diamonds were discovered at Bingara, again in Tertiary leads. Although the finders, miners M'Caw (sometimes spelled M'Call, or M'Caul) and Wescott, tried to keep it a secret, they finally had to sell some diamonds when their supplies and cash ran out. A diamond rush soon followed.

Because many of the early diamond miners were gold prospectors who just happened on the diamonds, early extraction techniques were based on those that were successful for gold. However, the specific gravity of diamond is only about 3.5, less than one-fifth that of gold, so panning and washing for diamonds was inefficient. A horse-powered "puddler" converted diamond-bearing dirt into a mixture of mud and boulders; the boulders were removed manually and the mud sluiced into boxes, where the panning occurred. "Rich ground" yielded about 2 carats of diamonds per cubic yard, roughly 4.5 diamonds per carat. Recorded production between the rush's beginning in 1872 and its end in 1874 was about 600 carats. In 1883, further exploration by Charles Rogers led the Australian Diamond Mining Company to resume operations. Various 19th-century "puddling" machines are described in this article, the first of a two-part series. *MLJ*

Diamonds in South Australia. G. Clarkson, *Australian Gold Gem & Treasure*, Vol. 10, No. 5, May 1995, pp. 27–29.

Alluvial diamonds have been found in the state of South Australia, and the geologic setting promises further diamond discoveries. Diamonds were first found at Echunga, near Adelaide, in 1859; by 1900, a total of 50 "salable" diamonds had been recorded. Another find occurred in 1987. Permian conglomerates in the Springfield Basin have yielded 128 diamonds, accompanied by indicator garnets with their fragile kelyphitic rinds intact, which suggests that they did not travel very far. At Eurelia, 140 diamonds have been found, associated with kimberlites.

Lamprophyric rocks, including kimberlites, are widespread in South Australia. The most important are: Eurelia (Jurassic kimberlite dikes), Terowie-Manunda (dikes and pipes), the Eyre Peninsula (Jurassic kimberlite pipes and dikes, including an altered monticellite kimberlite complex), Truro (Ordovician lamproites), Radium Hill (Ordovician lamprophyre dikes), Port Augusta (micaceous kimberlite sills), and Mulgathing (mica-peridotite plugs and sills associated with kimberlite). Exploration of some of these regions is under way.

The article includes a map of South Australia that shows these localities and regional geologic structures. *MLJ*

Emeralds from Somondoco, Colombia: Chemical composition, fluid inclusions and origin. A. Kozlowski, P. Metz, and H. A. Estrada Jaramillo, *Neues Jahrbuch für Mineralogie, Abhandlungen,* Vol. 159, No. 1, 1988, pp. 23–49.

This description of the geologic setting and mineral associations of emerald occurrences at Somondoco, Colombia, first summarizes earlier research. It stresses the occurrence of emeralds in carbonatic veins and pockets in fractured and brecciated zones controlled by faults in the San Fernando fault system.

For their study, the authors used electron microprobe, emission spectroscopy, and infrared absorption, along with transmitted-light microscopy and thermogravimetry, to analyze the chemical composition and fluid inclusions of seven dark green to near-colorless beryls from one mine at Achiote, Chivor/Somondoco. This testing was also done to explain the growth conditions of the emeralds.

Backed by their analysis of the inclusions, Kozlowski et al. argue that the beryllium-poor host rocks contain enough Be and Cr for the rich emerald mineralization at Somondoco, and that the origin of the emeralds can be easily explained by local migration processes. Thus, they dispute the hypothesis of an "endogenous deep seated source for beryllium" proposed by A. A. Beus and D. A. Mineev in 1972. *RT*

Investment in mining in India. H. Govind, *Mining Magazine,* Vol. 173, No. 1, July 1995, pp. 22–23.

A new minerals policy announced in March 1993 and legislated in 1994 selectively opened mining in India to participation by foreign and domestic private investors. Relaxed mining laws and tax breaks now make it easier for foreign capital and expertise to help mine several nonfuel resources, including diamonds and gold.

All new mining leases will be issued for a minimum of 20 years and a maximum of 30. Existing leases now may be renewed for 20 years, twice as long as previously allowed, with further extensions possible. Prospecting licenses may be granted for periods up to three years, with extensions for a total of five years possible; the amount of material that may be extracted under prospecting leases has also been increased. Other investment-attractive changes to the mining laws are also described in this article.

The four principal diamond "belts" in India are listed as: the Ramkheria-Hirappur conglomerate belt in Madhya Pradesh, the Vajrakarur kimberlite belt in Andhra Pradesh, and kimberlites at Panna (Madhya Pradesh) and near Raipur. *MLJ*

Nephrite from Chuncheon, Korea. Won-Sa Kim, *Journal of Gemmology,* Vol. 24, No. 8, pp. 547–550.

Since 1976, the Chuncheon area northeast of Seoul, Korea, has annually produced around 80,000 to 90,000 kg of nephrite jade. The material is only rarely deep green; most ranges from "greenish white" to pale yellowish green or pale green. Chemical analysis of four samples indicated that this nephrite is at the tremolite end of the tremolite-actinolite series, with Mg contents appreciably higher than Fe. These results are consistent with the pale green color. Other properties are in agreement with those for tremolite. Impure material (as is common for nephrite) contains minor amounts of calcite, diopside, and chlorite. Dyed green nephrite from this source is now on the market: It exhibits a marked absorption band at 630–650 nm, whereas undyed Chuncheon nephrite has no distinctive absorption features. *CMS*

The reported benitoite occurrence in Texas—doubtful. A. Smith, *Mineral News,* Vol. 11, No. 5, May 1995, p. 5.

The first edition of the *Encyclopedia of Minerals* by Roberts et al. (1974) lists the Eocene sands of southwest Texas as a source for benitoite. Mr. Smith can find no evidence for benitoite occurring there, however, and suggests that the authors (or an uncited primary reference) may have confused benitoite with *bentonite*, an industrially important clay mineral known to occur in that area. *MLJ*

An unusual sapphire-zircon-magnetite xenolith from the Chanthaburi gem province, Thailand. R. R. Coenraads, P. Vichit, and F. L. Sutherland, *Mineralogical Magazine,* Vol 59, No. 3, 1995, pp. 465–479.

The geologic origin of Thailand's renowned gem corundum (sapphire and ruby) and other gemstones (e.g., zircon) associated with alkali basalts is problematic. Hence, any clue that might shed light on this subject will receive close scrutiny. This explains why such a detailed study was conducted on a small (1.5 cm, 0.6 inch) xenolith found in tailings from a mine near Khao Wua, about 7 km northwest of Chanthaburi.

The xenolith consists predominantly of aluminum- and titanium-rich octahedral magnetite that has exsolved (broken down) into hercynite, magnetite, and hematite during cooling from the original magma source; it also contains some sapphire and zircon crystals. Minor amounts of jarosite-alunite possibly represent an iron sulphide immiscible liquid in the original magma. U-Pb dating of the 2 mm zircon crystal in the xenolith yielded an age of 1–2 million years, which falls within the range of radiometric ages previously obtained for zircons and alkali basalt volcanism in this area. Etch pits on the exposed surfaces of the xenolith indicate that it was out of equilibrium (i.e., in the process of being dissolved) within the (alkali basalt) magma that was transporting it to the surface.

The authors believe that the xenolith—and sapphire and associated minerals—crystallized from some magma related to, but distinct from, the alkali basalt activity. The chemical compositions of the xenolith and its minerals suggest pegmatite-like crystallization in a silica-poor magma formed in the deep crust or upper mantle. Similarities with the occurrence of gem corundums in eastern Australia are noted. Because of the mineral associations observed in this xenolith, it is suggested that the recognition of zircon and magnetite in basalt, soil, or in an alluvial drainage system would be a positive indicator for sapphire. *AAL*

Women in small-scale mining in Zambia. P. Mundia, *Geoscience and Development,* No. 1, November 1994, pp. 12–13.

Women are involved in the small-scale mining of many Zambian resources, including tin, salt, copper, limestone, and gemstones. Women are mine owners, sorters, "knockers" (people who cob rough), and cooks. Most are involved in illegal mining, but women control 27 out of 121 prospecting and mining licenses granted by the Zambian government for aquamarines, amethysts, or emeralds. Among the constraints on women's full participation in this sector are: lack of technical knowledge, difficulties in disciplining male employees, time and mobility constraints due to families, and social-cultural attitudes. The author recommends that a revolving loan fund be set up to support women miners, and that assertiveness training be included in the free technical training that the Zambian government already provides. *MLJ*

JEWELRY HISTORY

Head-dresses of the Tibetan Nyinba in Nepal. H. Gabriel, Arts of Asia, Vol. 25, No. 4, 1995, pp. 90–95.

The intricately designed *taikor* is a large ceremonial headdress worn by the Nyinba people of Nepal for special occasions. It is part hat and part jewelry. Reflections of a family's wealth, these head-dresses are handed down from generation to generation. Many of them were brought from Tibet several centuries ago, when the ancestors of the Nyinba migrated to Nepal. Thus, they are seen as visible evidence of the Tibetan roots of their owners.

Often, the upper side of this boat-shaped head-dress is decorated with turquoise, coral, pearls, gold, and silver. (Turquoise, however, is the most abundantly used gem material here and in all Tibetan jewelry.) Less-opulent head-dresses contain brass domes. The *taikor* also features a fringe of metal and coral beads that falls over the wearer's forehead.

This article discusses the use of turquoise and other gem materials and precious metals, including their symbolism to the Nyinba people. Metal techniques observed in this ritual headgear include repoussé and chasing in finely articulated detail. The relationship of the *taikor* to the ritual headgear of other closely related tribes is also examined. *JEC*

PRECIOUS METALS

Platinum demand up 11% in 1994. M. K. Golay, *National Jeweler*, July 1, 1995, p. 30.

Demand for platinum was up 11%—to a record 4.51 million ounces—in 1994 because of substantial growth in demand by the jewelry and automobile industries, according to the Johnson Matthey Company. Platinum supplies rose 3%, to 4.53 million ounces. Declining shipments from South Africa (down 6%, to 3.16 million ounces) were offset by a sizable jump in Russian sales (up 49%, to 1.01 million ounces).

The average price of platinum in 1994 was up 8%, to $405.25 per ounce. Worldwide demand for platinum jewelry rose 7%, to 1.72 million ounces, stimulated by Japan's increased fabrication of pure platinum jewelry. Growth in high-technology and environmental applications was responsible for increased industrial demand, a 15% jump to 800,000 ounces. Demand for platinum in physical investment products rose 90,000 ounces in 1994, to 395,000 ounces. *MD*

Sales of gold jewelry up 6.3% in first half. M. K. Golay, *National Jeweler*, October 1, 1995, p. 26.

Gold jewelry enjoyed its 14th consecutive quarter of sales increases in the second quarter of 1995, according to the World Gold Council. Total U.S. gold-jewelry retail sales topped $3.8 billion in the first half of 1995, up 6.3% over the same period in 1994. Unit volume jumped even more—9.4%—to more than 43.6 million units. These results exceeded the 5.2% rise in U.S. retail sales during the same period. Sales of gold jewelry were up across all retail distribution channels in the first half of 1995, according to the report.

Discount stores continued to outperform all other types; dollar sales went up about 19% as compared to the first half of 1994. Independent jewelry stores had an increase of 6.5% in dollar sales. Chain jewelry stores matched U.S. retail sales with a 5.2% increase. Department stores increased 3.8% over the first half of last year. However, catalog showrooms lagged below the category average, with dollar sales up just 2.3% over the first half of 1994.

All merchandise classifications had greater dollar sales in the first half of 1995. Sales of earrings were up 13.9%; charms, 15.9%; bracelets, 6.2%; and neck chains, 3.2%. Gold wedding rings, non-wedding rings, and non-chain necklaces increased 5.0%, 9.4%, and 5.6% (respectively) in dollar volume over the comparable period in 1994. *MD*

Why gold is the noblest of all metals. B. Hammer and J. K. Nørskov, *Nature*, July 20, 1995, pp. 238–240.

This interesting solid-state physics paper compares surface reactivities of four metals—nickel (Ni), platinum (Pt), copper (Cu), and gold (Au). Gold is the "most noble" metal because it is the least reactive toward atoms or molecules in a liquid or gas at the interface with its surface. (Alloy formation is a separate issue that does not affect "nobility.")

The authors distinguish between the ability of a metal to form and break bonds at the surface, and its ability to form new compounds or be dissolved. To look at bonds, they examine bonding between a hydrogen molecule, H_2, and each metal.

A second factor in "nobility" is how tightly the *d* orbitals are bound to the nucleus of the metal atom. This determines how easily metal-metal bonds break to make compounds with other (nonmetallic) elements.

Au is "noble" in both respects, so it is the "most noble metal;" Pt is "noble" with regard to compound formation. It is a good metal for jewelry purposes, but acts as a catalyst with H_2 and other gases. Cu is noncatalytic but forms compounds (e.g., tarnishes) easily. Ni both shows catalytic activity and can tarnish.

This paper nicely introduces surface properties of metals; however, some background in physical chemistry or solid-state physics is probably necessary to understand it all. *MLJ*

World silver demand exceeds supply in 1994. *National Jeweler*, July 1, 1995, p. 30.

Demand for silver in 1994 exceeded the amount mined for the fifth consecutive year, according to *World Silver Survey*, a publication of the Silver Institute. The reported deficit was 150.2 million ounces.

Silver has three major use categories—industrial/decorative, jewelry/silverware, and photography. The institute calls coins and medals a fourth category. Demand increased in three of the four sectors, but worldwide fabrication demand actually declined 1.5%, or about 12 million ounces, during 1994. (The article does not say which sectors are considered "fabrication" sectors.) This decline resulted primarily from lower jewelry and silverware use in Thailand and India. Although this market segment saw its second highest demand level ever, it still declined 15% over the all-time record year of 1993, when India's use of silver for jewelry and silverware jumped over 100%. Total silver supply dropped 3.9% in 1994. Mine production was down 5% from 1993 to 1994 (468.8 million ounces to 444.2 million ounces). *MD*

SYNTHETICS AND SIMULANTS

AGEE hydrothermal synthetic emeralds. H. A. Hänni and L. Kiefert, *JewelSiam*, Vol. 5, No. 5, 1994, pp. 80–85.

This article studies a relatively new synthetic emerald that appeared on the market in mid-1994. After giving a short history of flux- and hydrothermally grown emeralds, the authors describe their analysis of six so-called AGEE emeralds. The distributor, A G Japan Ltd [sic], says that its emeralds are actually Colombian rough that has been crushed into a fine powder, purified by lasers, and then hydrothermally grown. The authors did not find any mineral inclusions typical of natural emeralds (mica flakes, chromite grains, tremolite needles), but they did find angular, chevron-shaped growth patterns, color zoning, and high chlorine concentrations (with the last probably the "most secure" proof of a synthetic origin). The AGEE samples are similar to—but more "impure" than—synthetic emeralds produced by Biron International. The authors speculate that these synthetic emeralds might be lower-quality Biron synthetic emeralds that are being resold by A G Japan. *[Editor's note: See related abstract in this issue—"Synthetic Emeralds called AGEE."]* *CEA*

Can diamonds be manufactured? *Mining Journal, London*, June 2, 1995, p. 407.

This historical note from the May 1895 *Mining Journal* deserves to be quoted in its entirety:

"*Can Diamonds be Manufactured?* Professor F.W. Clarke in an interview relative to the probable manufacture of diamonds of marketable size stated that he entertained no doubt whatever on the matter, and that he firmly believed that this will be done soon. Moissan, in Paris, has manufactured diamonds by melting wrought iron together with carbon, and permitting the mixture to cool very slowly. Under these conditions the carbon became crystallised. Simultaneously Kroutschoff in St. Petersburg, has got diamond crystals by a similar process."

This abstractor (MLJ) believes that the material produced was probably silicon carbide, which was named *moissanite* for "Moissan, in Paris" when it was later discovered in the Canyon Diablo meteorite (*Dana's System of Mineralogy*, 7th ed., 1944, Vol. 1, pp. 123–124). *MLJ*

Diamonds grown from liquid at 1 atm. *Diamond Industry Week*, Vol. 2, No. 37, September 25, 1995, p. 1.

Scientists at Pennsylvania State University have demonstrated that diamonds can be precipitated out of liquid-metal alloys containing dissolved carbon (up to 70%) and hydrogen. Alloys of iron, nickel, manganese, silver, gold, and tin have been examined; diamond progressively precipitates out of the carbon-rich alloys as temperatures decrease from about 1,000°C. This opens the possibility of diamond growth by the Czochralski process. *MLJ*

An examination of "serendipitous" synthetic zincite. R. C. Kammerling and M. L. Johnson, *Journal of Gemmology*, Vol. 24, No. 8, pp. 563–568.

Recently, gem-quality synthetic zincite was created by accident in a kiln used to produce zinc-based paint in Silesia, Poland. Such material has been produced—also accidentally—in the United States. Crystals and faceted stones of the transparent Silesia material are being sold on the gem market. It ranges from medium light yellow through orange to dark reddish orange in color. Gemological properties are consistent with (or very close to those for) natural zincite, a rare material. However, the natural material is usually less transparent and more brownish. In addition, chemical analyses for natural zincite indicated minor impurities of Mn and/or Fe, whereas this synthetic zincite revealed only Zn when analyzed with energy-dispersive X-ray fluorescence (EDXRF). Electrical conductivity (observed in the darkest-color sample) suggests that the color is due to band-gap absorption from defect states, not from Mn (as has been previously proposed). *CMS*

Kobe single crystal diamond update. *Diamond Industry Week*, September 25 1995, p. 1.

Kobe Steel, in Japan, has a process for growing single-crystal diamond thin films by chemical vapor deposition heteroepitaxially (i.e., on a nondiamond matrix). However, the matrix required is single-crystal platinum, and there is still strain caused by the slightly different lattice sizes of platinum as compared to diamond. Single crystals of an iridium-platinum alloy might have a lower lattice mismatch, creating less strain and allowing the manufacture of larger and more perfect synthetic diamond thin films. *MLJ*

Russians plan to produce diamond via explosive compaction in unused wind tunnel. *Diamond Depositions: Science & Technology*, Vol. 5, No. 6, 1995, pp. 9–10.

In nature, diamonds are produced in both static and dynamic high-pressure environments, including (in the latter category) meteorite impacts. Russian scientists from the Central Scientific Research Institute for Machine Building intend to convert an unused wind tunnel at the TsNIIMash ballistic missile complex, in Kalinin, into a chamber for producing diamonds by dynamic means.

The 200-m-long, 0.5-m-wide chamber will be divided into two segments by a steel disk; one side is evacuated, the other filled with an explosive mixture of hydrogen and oxygen gases. Ignition of the gases rams the stainless-steel disk into a cast-iron target at speeds reaching 3.3 km per second (7,380 miles per hour), which converts trace amounts of carbon in the cast iron into diamond particles. Yields of 15,000 carats per shot—0.83 wt.% of the cast-iron target—are predicted. Future plans call for production of larger diamonds—as much as 2,000 carats each—by means of an undefined improvement in the process. MLJ

Synthetic emeralds called AGEE (in Japanese). Y. Kitawaki, *Gemmology*, Vol. 25, No. 303, December 1994, pp. 8–11.

Several years ago, synthetic emeralds that were commonly called AGEE in Japan started to appear in Japanese retail markets. They are distributed by A. G. Japan Ltd., who promotes the stones as "powdered Colombian emeralds . . . hydrothermally recrystallized . . . [with] no color nor chemicals are added . . . ." This article, which includes six photos, reports on the gemological properties of 16 "AGEE" stones randomly selected from the stock of a retail store and tested. Their color, size, and transparency were diverse. In fact, gemological tests revealed that the samples actually represented four different types of synthetic emerald: Biron, vanadium beryl, Russian hydrothermal, and flux. The author explains the characteristics of each type and warns readers to keep all types of synthetic emeralds in mind when dealing with so-called AGEE stones. *[Editor's note: See related abstract in this issue—"AGEE Hydrothermal Synthetic Emeralds."]* HN

MISCELLANEOUS

The miners law. J. L. Neff, Part I—*California Geology*, Vol. 47, No. 6, 1994, pp. 152–158; Part II—*California Geology*, Vol. 48, No. 1, 1995, pp. 10–21.

Most mining in the United States is governed by the Federal Act of May 10, 1872, which permits claims to a length of "vein, ledge, or lode," together with a specific area on each side of the vein. This act is controversial today for a number of reasons. One is that no royalties are paid to the federal government for claims made on federal land. A second is that the law has been (ab)used as a means to claim land on which to build houses rather than mines.

This long article, originally published in the *Idaho Law Review* (Summer 1983, Vol. 19, No. 3), traces the history of American mining law from its roots in 9th-century Saxony to court decisions in the 1980s. It contains much interesting information. For example, rules for making mine claims were originally lenient; this encouraged trained workers, and not serfs, to become—or stay—miners (a dangerous profession). Miners had their own courts in 17th-century Cornwall and 1850s California. Mining law in the United States was developed largely because of, and to regulate, mining in California. Later, laws were added to handle more recent developments, such as oil fields (at first, by defining them as large "lodes") and protection of the wilderness. MLJ

1994: The geosciences in review. J. F. Gilbert et al., *Geotimes*, Vol. 40, No. 2, February 1995, pp. 14–51.

This long review article summarizes recent developments in many fields of the Earth and planetary sciences. For gemologists, potentially relevant fields include metals and mining, industrial minerals, exploration geochemistry, mineralogy, mineral physics, metamorphic petrology, as well as general geoscience information. In the field of metals and mining, the most notable development in 1994 was the availability of investment capital in North America, which permitted many companies to restructure their debts and acquire newly privatized resources in Peru, Kazakhstan, and other countries. Diamonds are an industrial mineral, and the boom (and later lowering of expectations) in diamond mining in Canada was noted.

Most geochemical exploration in 1994 was for gold and diamonds. The most extensive was for kimberlite pipes (in Africa, Canada, Australia, Brazil, Greenland, Guyana, Finland, and the U.S. [Colorado]) and for alluvial diamond deposits (Ghana, Guinea, Mali, Namibia, Zaire, Brazil, Canada [Alberta], and Indonesia [Kalimantan]).

A major focus in mineralogy was the study of minerals and rocks at high pressures, including investigation of the subcontinental lithosphere through examination of xenoliths and investigation of residual phases from high-pressure metamorphic assemblages containing coesite. In mineral physics, a symposium at the California Institute of Technology discussed the origin and fate of volatiles (especially water) in the deep mantle. Recently developed techniques in metamorphic petrology make it possible to date metamorphism directly using Sm-Nd, Rb-Sr, and U-Pb isotopes in garnet-bearing rocks, including eclogites. The timing of the growth of porphyroblasts, relative to deformation times, may be possible; this line of study could lead to new understanding of the origin and emplacement of eclogitic diamonds.

As for information science, the average geoscience book published in the United States in 1994 cost $66 (with books published in continental Western Europe costing nearly $150 per title). MLJ

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SUBJECT INDEX

This index gives the first author (in parentheses), the issue, and the first page (plus "ff")of the article in which the indexed subject occurs. For Gem News (GN), Gem Trade Lab Notes (GTLN), and Letters (Let) sections, inclusive pages are given for the subject item. The reader is referred to the Author Index at the end of this section for the full title and the coauthors, where appropriate, of the articles cited. The pages covered by each issue are as follows: Spring (1–86), Summer (87–148), Fall (149–226), and Winter (227–304).

AUTHOR INDEX

This index lists, in alphabetical order, the authors of all articles that appeared in the four issues of Volume 31 of *Gems & Gemology*, together with the inclusive page numbers and the specific isssue (in parentheses). Full citation is provided under the first author only, with reference made from joint authors.

GEMOLOGICAL INSTITUTE OF AMERICA

A CHART FOR THE SEPARATION OF NATURAL AND SYNTHETIC DIAMONDS

PROPERTIES	NATURAL YELLOW Type Ia or Ib+IaA	SYNTHETIC YELLOW Type Ib or Ib+IaA *(Type Ib or IaA if irradiated and heat treated, or type IaA if heat treated at high pressure)*	NATURAL COLORLESS TO NEAR-COLORLESS Type Ia, IIa or IIb	SYNTHETIC COLORLESS TO NEAR-COLORLESS Type IIa or mixed type IIa+Ib+IIb	NATURAL BLUE Type IIb (see note below)	SYNTHETIC BLUE Type IIb or mixed type IIb+IIa	PROPERTIES
Color	Yellow (can range from grayish to greenish to orangy to brownish yellow); light to dark (may appear brown). Ia common, Ib+IaA much rarer.[FIG 1] *If irradiated and heat treated (at about 800° C or higher),*[FIG 10] *can be yellow (ranging from orangy to brownish yellow) (Ia) or pink to red (Ib+IaA); light to dark.*	Yellow (can range from greenish to orangy to brownish yellow); moderate to dark (may appear brown).[FIG 11] Ib common, Ib + IaA much rarer. *Ib or IaA treated – Orange to pink (or even red); moderate to dark; due to irradiation (and heat treatment to about 800° C if pink to red).*[FIG 20] *IaA treated – Yellow to greenish yellow to yellowish green; moderate; due to heat treatment (1700° to 2100° C) at high pressure.*[FIG 19]	Ia (common) – Colorless, or very faint yellow, brown, or green. IIa (much rarer) – Colorless[FIG 21], or very faint brown or gray. IIb (much rarer) – Colorless, or very faint gray.	IIa – Colorless to near-colorless.[FIG 31] Mixed type – Sometimes appearing very light gray, very light blue, very light yellow, or very light green due to the presence of impurities (boron, nitrogen, or nickel, respectively) in some small internal growth sectors.[FIG 32]	Blue to blue-gray; very light to dark.[FIG 41, 42] Note: Natural colorless or very light color (usually brown) Ia or IIa diamonds can be turned blue by irradiation treatment. Some rare Ia natural diamonds containing hydrogen as an impurity have a blue color. In both cases, their gemological properties are completely different from the blue, IIb synthetic diamonds seen to date.	Blue, light to dark (can also appear light greenish or grayish blue if small yellow internal growth sectors are present).[FIG 51]	Color
Size	Rough crystals to more than several 100 ct, and faceted stones to more than 100 ct.	Rough crystals up to 34 ct have been grown on an experimental basis, but most crystals are 1 to 2 ct or less. Cut stones are up to several carats, but typically less than 0.5 ct. *Treated synthetic diamonds seen to date are less than 1 ct, but could potentially be as large as untreated synthetic diamonds.*	Rough crystals to more than 100 ct, and faceted stones to more than 100 ct.	Rough crystals up to 3 ct have been grown on an experimental basis. Cut stones less than 1 ct to date.	Rough crystals to more than 100 ct, and faceted stones to more than 100 ct.	Rough crystals up to 1 ct have been grown on an experimental basis. Cut stones less than 1 ct to date.	Size
Shape of rough crystals	Octahedron (often modified by other crystal faces, often rounded, and sometimes twinned).[FIG 2] Some crystals display irregular growth or dissolution surfaces or shapes.[FIG 3] Ib + IaA diamonds may be cuboid.	Cuboctahedron (cube {100} plus octahedron {111}), possibly modified by other crystal faces (dodecahedral {110}, trapezohedral {113, 115});[FIG 12] with sharp edges and corners and flat surfaces; crystal faces often display dendritic (or fern-like) patterns, striations, raised edges, or other distinctive surface features not seen on natural diamonds.	Ia – octahedron (often modified by other crystal faces and rounded; sometimes twinned).[FIG 22, 23] Some crystals display irregular growth or dissolution surfaces or shapes.[FIG 23] IIa – crystals have an irregular shape.	Cuboctahedron (cube {100} plus octahedron {111}), possibly modified by other crystal faces (dodecahedral {110}, trapezohedral {113, 115});[FIG 33, 34] with sharp edges and corners and flat surfaces; crystal faces often display dendritic (or fern-like) patterns, striations, raised edges, or other distinctive surface features not seen on natural diamonds.[FIG 35]	Crystals usually irregular in shape[FIG 43]; rarely in the form of an octahedron. Some crystals display irregular growth or dissolution surfaces or shapes.	Cuboctahedron (cube {110} plus octahedron {111}), possibly modified by other crystal faces (dodecahedral {110}, trapezohedral {113, 115}); with sharp edges and corners and flat surfaces;[FIG 52] crystal faces often display dendritic (or fern-like) patterns, striations, raised edges, or other distinctive surface features not seen on natural diamonds.	Shape of rough crystals
Features seen with magnification							**Features seen with magnification**
Growth sectors	Only octahedral internal growth sectors present. On rare occasions, cloudy "cuboid" growth sectors may form a flower-like pattern in the center of a crystal.	Presence of more than one kind of internal growth sector (often a central sector in the shape of an octagon, surrounded by four octahedral and four cubic, and sometimes additional dodecahedral and trapezohedral, growth sectors). Arrangement of internal growth sectors is revealed by interrelated patterns of color, UV fluorescence or cathodoluminescence, and graining.[FIG 13, 14, 17, 18]	Only octahedral internal growth sectors present. On rare occasions, cloudy "cuboid" growth sectors may form a flower-like pattern in the center of a crystal.	Several internal growth sectors (octahedral, cube, dodecahedral, trapezohedral) revealed by zoning of the UV fluorescence or cathodoluminescence.	Only octahedral internal growth sectors present.	Presence of more than one kind of internal growth sector (often a central sector in the shape of an octagon, surrounded by four octahedral and four cubic, and sometimes additional dodecahedral and trapezohedral, growth sectors). Arrangement of internal growth sectors revealed by interrelated patterns of color, UV fluorescence or cathodoluminescence, and graining.	Growth sectors
Internal color distribution	Often even;[FIG 4] sometimes uneven with irregular-shaped ("blotchy") color zones,[FIG 5] or sometimes a darker yellow zone near the center of a crystal. *Treated – Sometimes even; occasionally uneven with color zoning (due to the treatment process) that follows the faceted shape of the cut stone. Treated pink diamonds often contain narrow, wedge-shaped yellow zones.*	Normally, uneven color distribution that is related to the arrangement of internal growth sectors and their differing impurity contents (arrangement may appear as square, octagon, cross shape, columnar, or funnel).[FIG 13] The degree of color zoning varies from subtle to distinct, usually with darker and lighter yellow (sometimes colorless) sectors.[FIG 15] *Synthetic diamonds subjected to irradiation and heat treatment exhibit a similarly arranged pink-or red-and-yellow color zoning resulting from a pink or red color being produced by treatment in certain internal growth sectors, while others remain yellow.*	Predominantly even, or not applicable.	Mixed type – Occasionally faint uneven color distribution may be visible due to small type Ib (yellow) and/or type IIb (blue) internal growth sectors. When present, these small growth sectors may produce a very light gray, blue, yellow, or green color seen face-up in a cut stone.	Often even; sometimes indistinct blue/colorless zoning.[FIG 44]	Usually uneven color distribution related to the arrangement of internal growth sectors with differing impurity contents. The degree of color zoning varies from subtle to distinct, usually with lighter (nearly colorless) and darker blue sectors. May form a cross-shaped pattern.[FIG 53–55]	Internal color distribution
"Graining"	Graining (sometimes yellow or brown) along planes parallel to the octahedral crystal faces.[FIG 4, 6] May form a cross-hatched or "tatami" pattern.	Graining planes along boundaries between internal growth sectors, or as parallel planes within a sector.[FIG 15] Graining planes often intersect in patterns. "Stopsign" (octagonal) surface (seen with reflected light) and "hourglass" internal (seen with transmitted light) graining patterns or portions of these patterns often seen[FIG 14]; other graining patterns possible.	Graining (sometimes colored) often along planes parallel to the octahedral crystal faces.[FIG 24, 25] May form a cross-hatched or "tatami" pattern.	IIa – Little or no graining planes seen (due to the relative absence of impurities in internal growth sectors and, as a result, little or no difference in R.I. between growth sectors). Mixed type – Weak graining sometimes seen.	Generally none; occasionally weak whitish or "phantom" graining.[FIG 46]	Graining planes along boundaries between internal growth sectors, or as parallel planes within a sector. Graining planes often intersect in patterns. "Stopsign" (octagonal) surface (seen with reflected light) and "hourglass" internal (seen with transmitted light) graining patterns or portions of these patterns often seen; other graining patterns possible.	"Graining"
"Strain" (Anomalous double refraction)	Weak to strong anomalous double refraction, with various interference colors, along planes parallel to the octahedral crystal faces, giving a cross-hatched appearance. When viewed in other orientations, this may appear as a mosaic of various interference colors.	Weak anomalous double refraction, sometimes in the form of a black cross.	Weak to strong anomalous double refraction, with various interference colors, often along planes parallel to the octahedral crystal faces, giving a cross-hatched appearance.[FIG 26] When viewed in other orientations, this may appear as a mosaic of various interference colors.	Weak anomalous double refraction, sometimes in the form of a black cross.	Weak anomalous double refraction, with various interference colors, sometimes seen along planes parallel to the octahedral crystal faces, giving a cross-hatched appearance.[FIG 47] When viewed in other orientations, this may appear as a mosaic of various interference colors.	Weak anomalous double refraction, sometimes in the form of a black cross.	"Strain" (Anomalous double refraction)
Inclusions	Mineral inclusions occasionally present, consisting of diamond or transparent colorless or colored minerals (e.g., olivine, garnet, spinel, pyroxene).[FIG 7] Ib diamonds often contain dark needle- or plate-like inclusions.[FIG 8]	Metallic (reflected light) or opaque black (transmitted light) inclusions of flux metal often seen, in sizes up to 1 mm. Often rounded or elongate. Occur either isolated or in small groups. Often parallel to the outer surface of the rough crystal, or along boundaries between internal growth sectors.[FIG 14, 15, 16]	Mineral inclusions occasionally present, consisting of diamond or transparent colorless or colored minerals (e.g., olivine, garnet, spinel, pyroxene).[FIG 27, 28]	Metallic (reflected light) or opaque black (transmitted light) inclusions of flux metal often seen, in sizes up to 1 mm.[FIG 36] Often rounded or elongate.[FIG 37] Occur either isolated or in small groups. Often parallel to the outer surface of the rough crystal, or along boundaries between internal growth sectors.	Usually free of mineral inclusions.	Metallic (reflected light) or opaque black (transmitted light) inclusions of flux metal often seen, in sizes up to 1 mm[FIG 57]. Often rounded or elongate. Occur either isolated or in small groups. Often parallel to the outer surface of the rough crystal, or along boundaries between internal growth sectors.	Inclusions
Other features	Frequently contain fractures and/or cleavages that may exhibit etching or other evidence of dissolution.	Clouds of tiny "pinpoint" inclusions may be seen, but are not diagnostic for identification purposes. Generally free of fractures and cleavages.	Frequently contain fractures and/or cleavages that may exhibit etching or other evidence of dissolution.	Clouds of tiny "pinpoint" inclusions may be seen, but are not diagnostic for identification purposes. May be free of fractures and cleavages.	Occasionally contain fractures and/or cleavages that may exhibit etching or other evidence of dissolution.[FIG 45]	Clouds of tiny "pinpoint" inclusions may be seen, but are not diagnostic for identification purposes.[FIG 56] Generally free of fractures and cleavages.	Other features
Fluorescence to ultraviolet (UV) radiation							**Fluorescence to ultraviolet (UV) radiation**
Long-wave (LW) UV fluorescence (color and intensity)	Ia – Sometimes none visible; if fluorescent, usually blue or yellow, occasionally orange, rarely green; weak to very strong. Ib+IaA – Often none visible; sometimes yellow or orange; weak. *Ia treated – Yellow to green; weak to strong.* *Ib+IaA treated – Orange; often with narrow, wedge-shaped green zones; weak to very strong.*	Ib – none visible. Ib+IaA – yellow or yellow-green; weak to strong.[FIG 17] *Ib or IaA treated – strong green plus weak orange in different internal growth sectors, or just weak orange.* *IaA treated – greenish yellow, sometimes yellow, very strong.*	Rarely, none visible; or blue, yellow, or orange; weak to very strong.[FIG 29]	None visible.	Usually none visible; rarely orange to orange-red; weak to moderate.	None visible.	Long-wave (LW) UV fluorescence (color and intensity)
Short-wave (SW) UV fluorescence (color and intensity)	Ia – Sometimes none visible; if fluorescent, usually blue or yellow, occasionally green, rarely orange; weak to very strong. Ib+IaA – Often none visible; sometimes yellow or orange; weak. *Ia treated – Yellow to green; weak to strong.* *Ib+IaA treated – Orange with narrow, wedge-shaped green zones; weak to very strong.*	Ib – none visible, or yellow to yellow-green; weak to moderate. Ib+IaA – yellow or yellow-green; weak to strong. *Ib or IaA treated – strong to very strong green plus weak orange in different internal growth sectors, or just weak orange.* *IaA treated – greenish yellow, strong.*	None visible; or blue, yellow, or orange; weak to strong.	Yellow, green-yellow, or orange-yellow; weak to strong.[FIG 39]	Usually none visible; occasionally yellowish to bluish white, rarely orange to orange-red; weak to moderate.[FIG 48]	Yellow or green-yellow, weak to moderate.[FIG 59]	Short-wave (SW) UV fluorescence (color and intensity)
Relative intensity of UV fluorescence	Ia – almost always LW is stronger than SW. Ib+IaA – LW is stronger than SW, rarely SW is stronger than LW or LW=SW. *Ia treated – LW is stronger than SW.* *Ib+IaA treated – LW=SW or LW is stronger than SW.*	Ib or Ib+IaA – SW is stronger than LW *Ib or IaA treated – LW=SW or SW is stronger than LW.* *IaA treated – LW is stronger than SW.*	Generally LW is stronger than SW or LW=SW; very rarely SW is stronger than LW.	SW is stronger than LW.	Typically SW is stronger than LW.	SW is stronger than LW.	Relative intensity of UV fluorescence
Distribution of UV fluorescence	Usually even, rarely uneven. Hydrogen-rich natural diamonds often show blue and yellow fluorescent zones arranged in a geometric pattern. *Ia treated – Usually even.* *Ib+IaA treated – Often uneven, with larger zones of orange fluorescence separated by narrow, wedge-shaped zones of green fluorescence.*	Uneven distribution; duplicates internal growth-sector arrangement, often with a square or octagon plus a cross-shaped pattern, with some sectors fluorescing and others showing no visible fluorescence.[FIG 17] Within a growth sector, fluorescence may appear as banding that parallels the graining.	Usually even[FIG 29]; sometimes uneven.	Uneven distribution; duplicates internal growth-sector arrangement, often with a square or octagon plus a cross-shaped pattern, with some sectors fluorescing and others showing no visible fluorescence.[FIG 39] Within a growth sector, fluorescence may appear as banding that parallels the graining.	Usually even.	Uneven distribution[FIG 59]; duplicates internal growth-sector arrangement, often with a square or octagon plus a cross-shaped pattern, with some sectors fluorescing and others showing no visible fluorescence. Within a growth sector, fluorescence may appear as banding that parallels the graining.	Distribution of UV fluorescence
Phosphorescence (color, intensity, and duration)	Occasionally yellow (LW and SW), weak to moderate, usually less than 15 seconds duration.	Ib or Ib+IaA – usually none; sometimes weak yellow or greenish yellow, lasting several seconds. *Ib or IaA treated – rarely weak green, lasting several seconds.* *IaA treated – yellow, moderate to strong (LW and SW); persistent – 30 to 60 seconds.*	Occasionally yellow (LW and SW), generally weak, lasting 30 seconds or less.	Always present; usually yellow or greenish yellow, moderate to strong (SW), and very persistent – lasting 60 seconds or more.	Very rarely bluish white (LW) and almost always bluish white (SW), rarely yellow, orange to orange-red[FIG 49]; weak to moderate; lasting less than 15 seconds.	Yellow, moderate to strong (SW), persistent – lasting 30 to 60 seconds.	Phosphorescence (color, intensity, and duration)
Other Characteristics							**Other Characteristics**
Luminescence to electron radiation—cathodoluminescence (color, intensity, and distribution)	Usually blue, sometimes other colors such as green to yellow-green; may form a cross hatched pattern or one related to the arrangement of octahedral internal growth sectors.[FIG 9] *Treated – Usually green, forms pattern related to the arrangement of octahedral internal growth sectors.*	Uneven distribution that duplicates the arrangement of internal growth sectors, with some sectors luminescing different colors (yellow, orange, blue, or green) and others showing no luminescence.[FIG 18] Generally more distinct than the UV fluorescence. Pattern of luminescence similar to that seen for UV fluorescence.	Usually blue, sometimes other colors; Ia – may form a pattern related to the arrangement of octahedral internal growth sectors.[FIG 30] IIa – may exhibit a complex network pattern or cross-hatched "tatami" pattern.	Uneven distribution which duplicates the arrangement of internal growth sectors, with some sectors luminescing different colors (yellow, blue, or green) and others showing no luminescence.[FIG 40] Generally more distinct than the UV fluorescence. Pattern of luminescence similar to that seen for UV fluorescence.	Usually blue[FIG 50], sometimes other colors; generally shows a complex network pattern or cross-hatched "tatami" pattern.	Uneven distribution which duplicates the arrangement of internal growth sectors, with some sectors luminescing different colors (yellow or green) and others showing no luminescence.[FIG 60] Generally more distinct than the UV fluorescence. Pattern of luminescence similar to that seen for UV fluorescence.	Luminescence to electron radiation—cathodoluminescence (color, intensity, and distribution)
Luminescence to visible light (color, intensity, and distribution)	Occasionally green or violetish blue; weak to strong; often follows graining planes. *Ia treated – occasionally green, weak to strong.* *Ib+IaA treated – occasionally orange with narrow, wedge-shaped green zones; weak to strong.*	Ib – none visible. Ib+IaA – green, weak to moderate, often uneven distribution that is related to the arrangement of internal growth sectors. *Ib or IaA treated – occasionally moderate green; rarely weak orange.* *IaA treated – none visible or green, weak to moderate, often uneven distribution that is related to the arrangement of internal growth sectors.*	When observed, generally blue, rarely green; usually even distribution.	None visible.	None visible.	None visible.	Luminescence to visible light (color, intensity, and distribution)
Optical absorption spectrum (hand-held type spectroscope)	Ia – one or more sharp absorption bands of the "Cape" series (415, and possibly 423, 433, 452, 465, and 478 nm), and sometimes weak 496 and 503 nm absorption bands. Ib+IaA – no sharp absorption bands. *Treated — One or more sharp absorption bands:* *Ia – 496, 503, and 595 nm bands.* *Ib+IaA – 503, 575, 595, 615, 625, and 637 nm bands.*	Ib – usually no sharp absorption bands; 658 nm band occasionally seen if the synthetic diamond is cooled. Ib+IaA – several sharp bands between 600 and 700 nm may be seen if the synthetic diamond is cooled (bands at 617, 627, 637, 647, 649, 658, 671, and 691 nm). *Ib or IaA treated – several sharp bands sometimes seen at 503, 527, 553, 575, 595, 617, 637, and 658 nm.* *IaA treated – sharp absorption bands sometimes seen at 473, 478, 481, 503, 511, 518, 527, 547, and 553 nm*	Ia – one or more sharp absorption bands of the "Cape" series (415, and possibly 423, 433, 452, 465, and 478 nm). IIa – no sharp absorption bands. IIb – no sharp absorption bands.	No sharp absorption bands.	No sharp absorption bands.	No sharp absorption bands.	Optical absorption spectrum (hand-held type spectroscope)
Other distinctive features	Not attracted by a magnet.	Maybe attracted by a strong magnet due to the metallic inclusions. Chemical analysis often reveals the presence of flux metals (such as nickel and/or iron).	Not attracted by a magnet. IIb – electrically conductive.	May be electrically conductive (if traces of boron are present). May be attracted by a strong magnet due to the metallic inclusions.[FIG 38] Chemical analysis often reveals the presence of flux metals (such as nickel and/or iron).	Electrically conductive. Not attracted by a magnet.	Electrically conductive. May be attracted by a strong magnet due to the metallic inclusions.[FIG 58] Chemical analysis often reveals the presence of flux metals (such as nickel and/or iron).	Other distinctive features

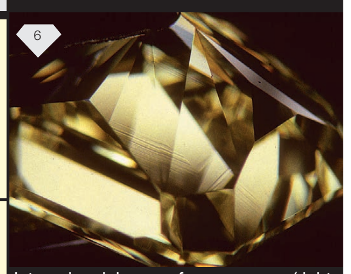

1 Occasionally the yellow color in untreated natural diamonds is highly saturated.

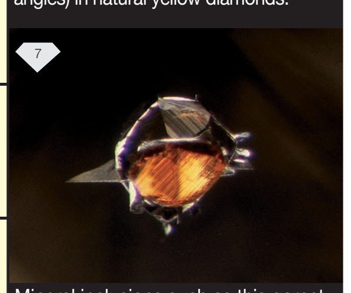

2 The typical octahedral shape of many natural diamond crystals differs from that of synthetic diamonds.

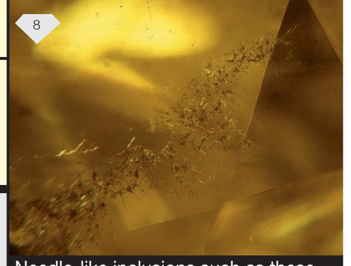

3 Natural yellow diamond crystals typically show evidence of etching and dissolution.

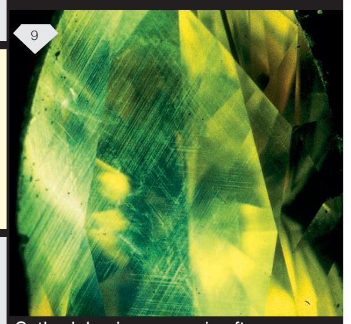

4 Even coloration and reflective internal graining may be seen in natural yellow diamonds.

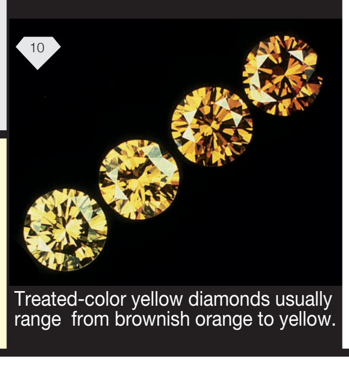

5 When uneven, color distribution in natural yellow diamonds tends to be blotchy.


6 Internal graining can form a square (right angles) in natural yellow diamonds.

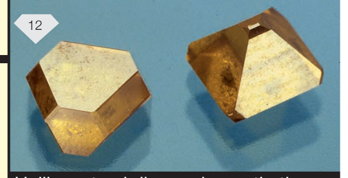

7 Mineral inclusions such as this garnet are proof that a diamond is natural. Mag. 20×.

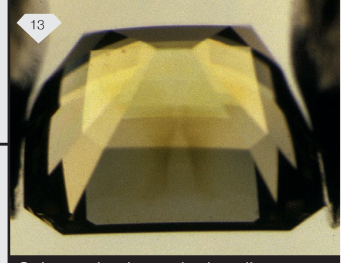

8 Needle-like inclusions such as these are often found in natural type Ib yellow diamonds.

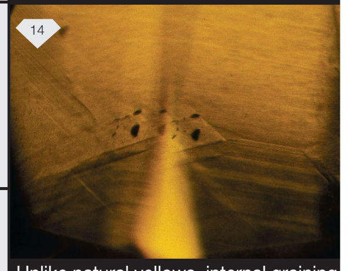

9 Cathodoluminescence is often cross-hatched in natural diamonds.

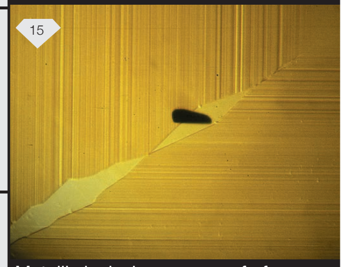

10 Treated-color yellow diamonds usually range from brownish orange to yellow.


11 Most synthetic yellow diamonds are highly saturated and darker (brownish) than natural.

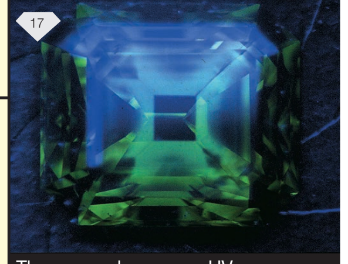

12 Unlike natural diamonds, synthetic diamond crystals (here, 0.78 and 0.88 ct) typically exhibit cube (in addition to octahedral) faces as well as flat surfaces and sharp edges and corners.

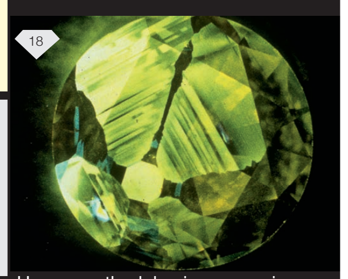

13 Color zoning in synthetic yellow diamonds is typically uneven, in geometric patterns that reflect impurity differences between internal growth sectors.


14 Unlike natural yellows, internal graining in synthetic yellows appears as intersecting lines. Note also the opaque metallic inclusions. Mag. 30×.

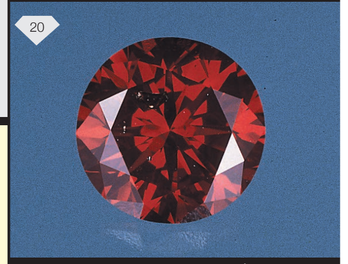

15 Metallic inclusions are proof of a synthetic diamond. Note also the distinctive internal graining and color zoning. Mag. 25×.


16 Metallic inclusions are often seen in synthetic diamonds. Mag. 20×.

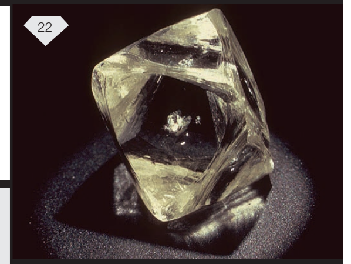

17 The uneven long-wave UV fluorescence in this yellow synthetic diamond reflects the distinctive arrangement of internal growth sectors.


18 Uneven cathodoluminescence is one of the most characteristic features of synthetic diamonds.

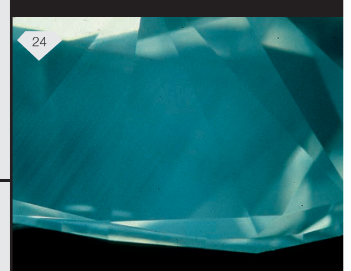

19 Heat-treated synthetic diamonds (here, 0.14 to 0.21 ct) typically are greenish yellow to yellow.

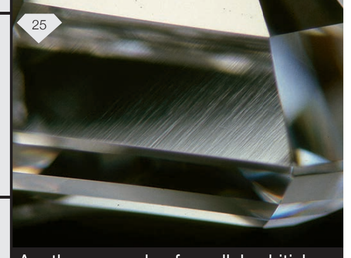

20 Red in synthetic diamonds (here, 0.55 ct) is produced by irradiation followed by heat treatment.

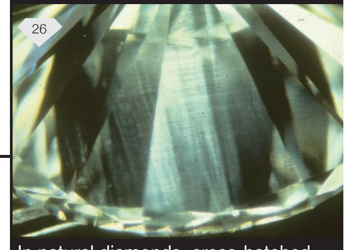

21 This faceted natural diamond is colorless and has good clarity.

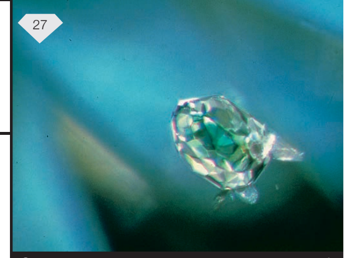

22 Natural diamond crystals often exhibit an octahedral shape.

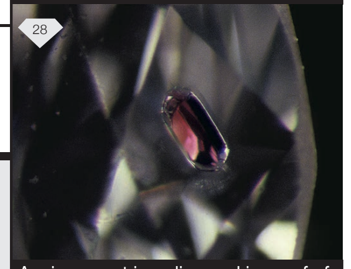

23 Etch features (including trigons) are common on natural diamond crystals.


24 In natural diamonds, whitish internal graining can occur in parallel planes.


25 Another example of parallel, whitish internal graining in a natural colorless diamond.


26 In natural diamonds, cross-hatched anomalous birefringence ("strain") can often be seen with crossed polarizing filters.


27 Chrome-diopside inclusions are proof of a natural diamond. Mag. 50×.


28 Again, garnet in a diamond is proof of natural origin.


29 Natural colorless diamonds typically have evenly distributed blue long-wave UV fluorescence.

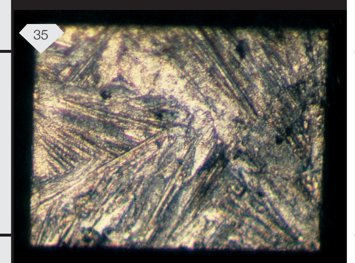

30 Natural colorless diamonds typically have even bluish cathodoluminescence but may display faint octahedral zoning.

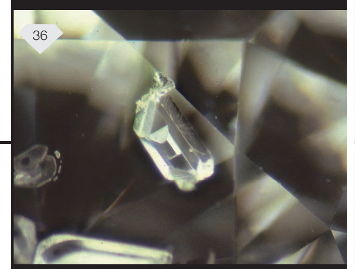

31 Faceted synthetic diamonds (here, 0.28 and 0.78 ct) can be near-colorless.


32 Near-colorless synthetic diamonds (here, 0.05 to 0.07 ct) may appear very light gray, very light blue, and very light green because some internal growth sectors are colored by impurities.

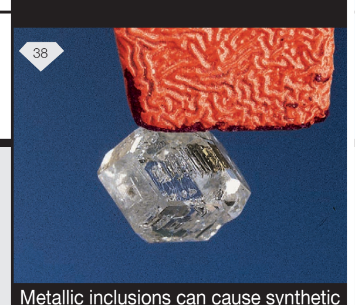

33 Synthetic diamond crystals (here, 0.50 ct) usually exhibit cube (as well as octahedral) faces and metallic inclusions.

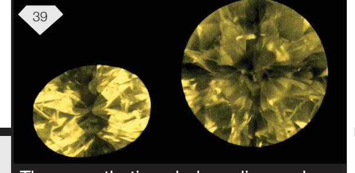

34 This cuboctahedral synthetic diamond crystal is almost free of inclusions.

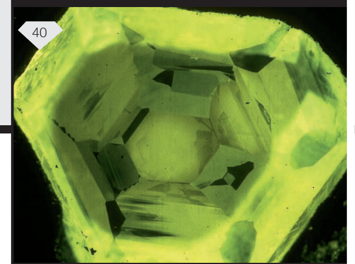

35 The surfaces of the crystal faces of synthetic diamond crystals may exhibit unusual patterns that are very different from the surface features of natural diamond crystals.


36 Metallic inclusions are usually the most obvious proof of synthesis.


37 Metallic inclusions may occur in a variety of shapes—here, elongate. Mag. 50×.

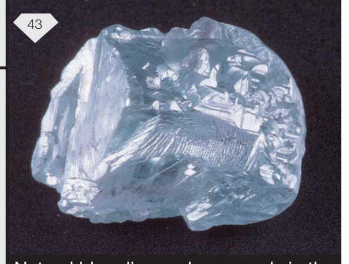

38 Metallic inclusions can cause synthetic diamonds to be attracted by a strong magnet.

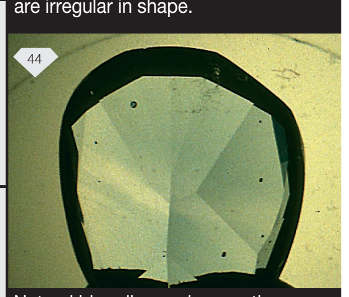

39 These synthetic colorless diamonds are inert to long-wave UV and fluoresce an uneven greenish yellow to short-wave UV.


40 In synthetic colorless diamonds, cathodoluminescence is almost always uneven and patterned.


41 Some natural diamonds have an intense blue color.


42 More commonly, natural blue diamonds are a paler hue.

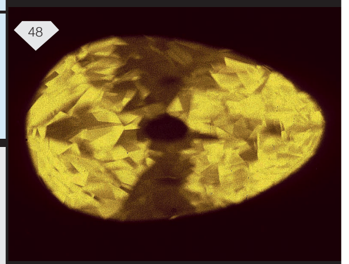

43 Natural blue diamonds are rarely in the form of an octahedron, but typically are irregular in shape.

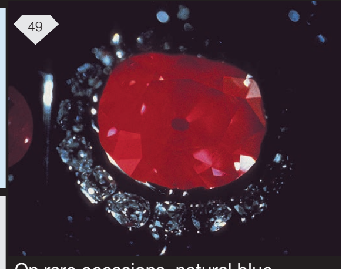

44 Natural blue diamonds sometimes show blue/colorless zoning.


45 Fractures and etch features are usually seen only in natural diamonds.

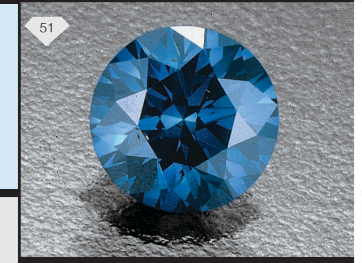

46 Whitish internal graining is also seen in natural blue diamonds. Mag. 21×.


47 This natural blue diamond exhibits a cross-hatched pattern of anomalous double refraction ("strain") when it is viewed between polarizing filters.

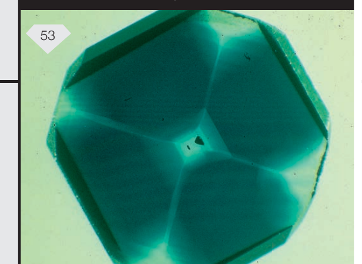

48 This natural blue diamond fluoresces yellow to a short-wave UV lamp.

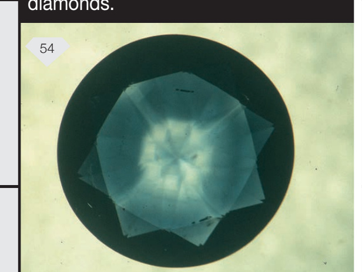

49 On rare occasions, natural blue diamonds display red phosphorescence when the ultraviolet lamp is turned off.

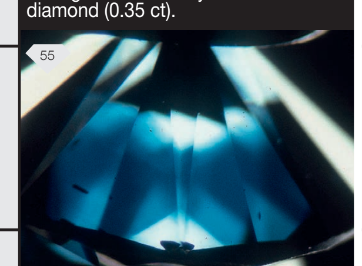

50 This natural blue diamond exhibits blue cathodoluminescence.

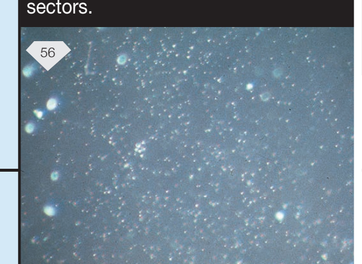

51 This 0.35-ct synthetic blue diamond is typical of those seen to date.

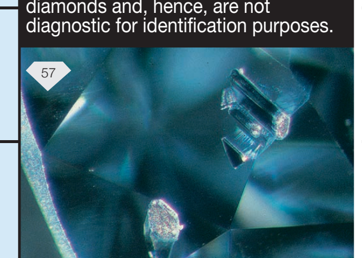

52 This blue crystal exhibits the flat octahedral and cube faces that are characteristic of synthetic diamonds.

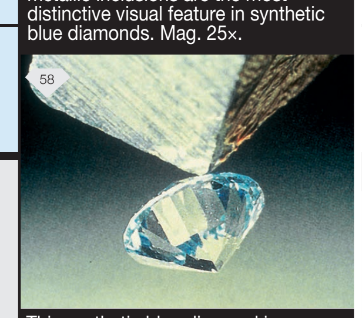

53 Uneven color zoning is a prominent characteristic of synthetic blue diamonds.

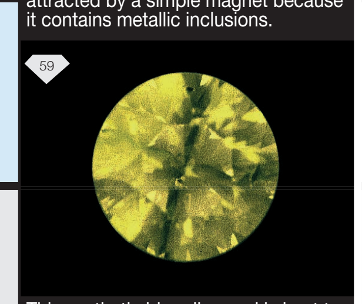

54 Another example of uneven color zoning in a faceted synthetic blue diamond (0.35 ct).

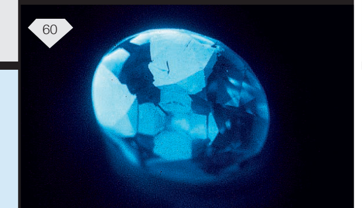

55 This uneven color zoning in a faceted synthetic blue diamond shows both blue and colorless internal growth sectors.


56 Many synthetic diamonds contain "pinpoint" inclusions that may appear similar to inclusions in natural diamonds and, hence, are not diagnostic for identification purposes.


57 As with other synthetic diamonds, metallic inclusions are the most distinctive visual feature in synthetic blue diamonds. Mag. 25×.


58 This synthetic blue diamond is attracted by a simple magnet because it contains metallic inclusions.


59 This synthetic blue diamond is inert to long-wave UV and fluoresce an uneven greenish yellow to short-wave UV.


60 In synthetic blue diamonds, cathodoluminescence is almost always uneven and patterned.

KEY TO INFORMATION

The information in this chart represents the key properties used in the separation of natural from synthetic diamonds. Only the most commonly observed gemological features are noted here. Not all features are seen in all synthetic diamonds; however, all synthetic diamonds examined to date exhibit one or more of the distinctive features mentioned in this chart. In general, natural diamonds exhibit greater variability in their gemological properties than do synthetic diamonds. This is due to the more complex history of formation of natural diamonds. Diamond type (i.e., Ia, IaA, Ib, IIa, IIb, mixed, etc. — as determined by infrared spectroscopy) is indicated for those physical properties that can be related directly to type. (For further information on diamond type, see Box A of E. Fritsch and K. Scarratt, "Natural-color nonconductive gray-to-blue diamonds," *Gems & Gemology*, Spring 1992, pp. 38-39.)

Information on natural or synthetic diamonds that have been treated in the laboratory to improve their color is presented in italicized text.

The information presented in this chart was gathered using the following methods:

Color: The range of hue, tone, and saturation of the synthetic and natural diamonds examined by GIA researchers using a fluorescent "daylight equivalent" light source.

Size: The weight of the rough crystals and faceted synthetic diamonds examined by GIA researchers since 1984, or the *reported* weights of synthetic diamonds grown thus far.

Magnification: Features seen with a standard binocular gemological microscope (with 10× to 40× magnification), and either transmitted or reflected illumination and/or fiber-optic lighting. When 20× or higher, magnification is indicated in the figure legends. Strain (anomalous double refraction) as seen when sample is viewed between crossed polarizing filters.

Ultraviolet (UV) fluorescence: Fluorescence colors observed in a darkened room using contrast-control glasses, a standard UV lamp unit, and, in some cases, a gemological microscope fitted with a UV lamp unit. The color hue and relative intensity of the UV fluorescence were both determined by visually comparing the sample with a set of natural diamonds that fluoresce various colors.

Cathodoluminescence: Luminescence colors observed in a darkened room, using a Nuclide ELM–2B luminoscope. This luminescence is produced in an evacuated chamber by exposing the diamond to an electron beam. During such exposure, the diamond may become heated above room temperature.

Optical absorption spectrum: Sharp absorption bands observed with a Beck prism spectroscope and a Discan digital-scanning spectroscope, with the diamond held at room temperature or cooled with a spray refrigerant.

Luminescence to visible light: Luminescence colors observed in a darkened room when the diamond is held over an intense visible-light source (such as a fiber-optic unit).

Phosphorescence: Luminescence colors observed in a darkened room when the UV lamp is turned off. An electronic timer was used to measure the time elapsed until the phosphorescence could no longer be seen.

Magnetism: Magnetic attraction determined by suspending subject sample with a fine plastic line and bringing a strong magnet toward it.

Electrical Conductivity: Ability of sample to conduct electricity as determined using a standard gemological conductometer.

ADDITIONAL FOOTNOTES

The number of gem-quality synthetic diamonds (both crystals and cut stones) examined by GIA researchers since 1984: yellow—108, blue—9, colorless to near-colorless—22. Thousands of natural diamonds of corresponding colors were examined during this same period.

Both natural and synthetic diamonds have the same index of refraction (RI), specific gravity (SG), and, in most cases, the same thermal conductivity. As such, these properties are not helpful for identification purposes.

This chart accompanies "A Chart for the Separation of Natural and Synthetic Diamonds" article by J. E. Shigley, E. Fritsch, I. Reinitz, and T. M. Moses, in *Gems & Gemology*, Vol. 31, No. 4 (Winter 1995). Published sources for much of the information in this chart are given at the end of that article.

CONTRIBUTORS
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Design and layout by: Christine Troianello

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