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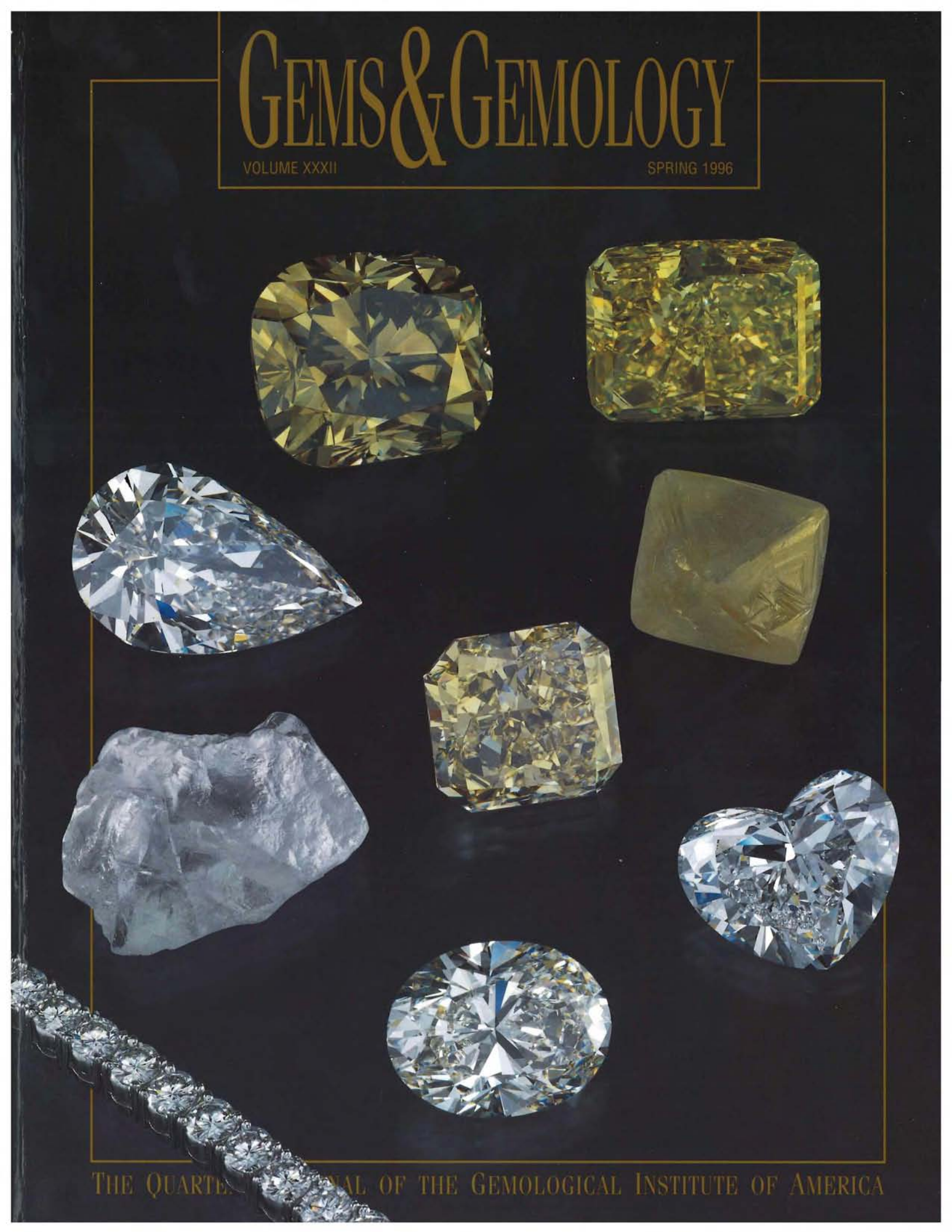

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GEMS & GEMOLOGY

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ABOUT THE COVER: Part II of the two-part series on the history of diamond sources in Africa continues to review discoveries in specific countries, and it explores the impact that activities on this continent have had on diamond geology, mining, and production worldwide. Although Africa's long dominance in world diamond production has diminished in recent decades, its steady output and large reserves ensure that it will remain the world's most important diamond-producing region. Certainly, African sources continue to produce a spectacular assortment of large, fine stones, like those shown here (clockwise from top left): a 60.03 ct cushion cut; an approximately 50 ct radiant cut, courtesy of Shaer and Spector; a 47.74 ct octahedron; a 20.31 ct heart shape, courtesy of Harry Winston Inc.; an 18.66 ct oval, courtesy of E. Schreiber Inc.; a 53.3 ct rough; and a 30.06 ct pear shape, courtesy of Julius Klein. The 27.43 ct radiant cut in the center is courtesy of Harry Winston Inc. The platinum bracelet contains 10.19 ct of diamonds and is courtesy of Kwiat Inc.

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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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The Quintessential Gemologist
Robert C. Kammerling
1947–1996

Robert C. Kammerling died suddenly and unexpectedly the morning of January 7, 1996. Bob had worked at GIA for 15 years, rising through the ranks to become Vice President for Research and Development of the GIA Gem Trade Laboratory. He had also poured his considerable intellect and prodigious work ethic into *Gems & Gemology*. He most recently served as senior editor of both the Gem Trade Lab Notes and Gem News sections, and he was one of the journal's most important contributors. Articles that he co-authored won awards in the *Gems & Gemology* Most Valuable Article competition every year for the last seven, and two of his articles won national awards for scientific writing. The loss to GIA and the journal is immeasurable.

For this editor, Bob was a friend who is deeply missed. Although not always the easiest person to work with, he was always brilliant, energetic, and extremely clever. No task was too hard, and no challenge too great. More importantly, he was intensely loyal to the G&G staff and, especially, to the vision we shared of what the journal should be: the source of accurate and useful information to gemologists in the trenches, the ones buying, selling, and appraising stones.

A native of the Chicago suburb of Oak Park and a graduate of the University of Illinois, Bob Kammerling worked and traveled extensively in Africa and Europe before he arrived at GIA's Santa Monica campus as a student in 1980. Hired as an instructor by now-President Bill Boyajian, Bob worked tirelessly to hone his skills as a gemologist, first in the classroom and later in such projects as revising GIA's A and B charts and writing (with Boyajian) the well-known *Gem Identification Laboratory Manual*. He rapidly distinguished himself as a researcher, showing a keen ability to focus on the most pressing issues facing the practicing gemologist. He participated in some of the earliest research on the treatment and identification of blue diffusion-treated sapphires, on the fracture filling of emeralds with synthetic polymers such as Opticon, and on filled diamonds. His latest contribution on filled diamonds, the identification chart and accompanying article that he co-authored with Shane McClure, won first place as the Most Valuable Article *Gems & Gemology* published in 1995; the chart has just been translated into Chinese and Korean.

But research to Bob was more than just reading articles and conducting laboratory experiments. He had a passion for gem localities that took him to some of the world's remotest areas—in Vietnam, Myanmar, and Egypt, to name a few. He always returned with reams of information and dozens of fine photos for the gemological literature. Sometimes his role was behind-the-scenes: When we needed additional shells and pearls for the Summer 1995 piece on pearling in Baja California, Bob jumped on a plane to Mexico, found the needed items (plus some new information), and brought them back in the space of a few days.

While gemology is a unique blend of both art and science, gemologists play a fundamentally moral role in our industry and in society as a whole. They seek to tell the truth about gems and, thus, preserve the integrity of these precious products. Bob Kammerling epitomized this principle. He used his special skills to find creative solutions to problems that threatened the industry. While he recognized that complex problems often require complex solutions, he felt that his—and GIA's—primary responsibility was to convert those solutions into tests that could be easily learned and applied by the jeweler/gemologist. To this end, he worked closely with both GIA Research and the GIA Gem Trade Laboratory, as well as with other laboratories in Europe and Asia. As a result, Bob has left a legacy to gemology that is enduring—a body of knowledge in diamonds and colored stones that is used daily in laboratories and jewelry stores all over the world. And he has left a team of gemologists and other researchers with the drive and skill to continue the research that he pursued so passionately.

Bob is survived by his daughter Loressa, his parents Dr. and Mrs. Erwin Kammerling, and a brother and a sister. To honor his memory and especially his contribution to gemology, *Gems & Gemology* is dedicating the Winter 1996 issue to Bob Kammerling. We hope to fill that issue with the types of articles that he thought most important, short papers on topics related to applied gemology: identification techniques, gem treatments, new natural or synthetic gem materials, and new localities. If you are interested in contributing to this issue (all papers must go through the standard review process), please contact me for further information. Join us in continuing the tradition for excellence in information that is Bob's gift to the field he so loved.

Alice S. Keller, Editor

A History of Diamond Sources In Africa: Part II

By A. J. A. (Bram) Janse

Following the history of diamond discoveries in southern Africa presented in Part I, this article discusses the history of diamond exploration and mining in East and West Africa. The first economic kimberlite outside South Africa was discovered in Tanzania (East Africa) in 1940, and major quantities of large, high-quality alluvial diamonds have been mined in West Africa since the mid-1930s. Early miners struggled with misconceptions about how diamonds formed and concerns as to the depth to which diamonds could occur in pipes. Mining developments and new diamond occurrences in Africa led to many of the key concepts in modern diamond geology. Although Africa's long dominance in world diamond production has diminished in recent decades, its steady output and large reserves ensure its continuing role as the most important diamond-producing region in the world, surpassing in overall impact even Australia and Russia.

ABOUT THE AUTHOR

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

Please see Acknowledgments at end of article.

Gems & Gemology, Vol. 32, No. 1, pp. 2–30.

For more than 50 years, diamond mining in Africa was restricted almost entirely to southern and central Africa (see Part I in Janse, 1995). Beginning in the mid-1920s, though, production started in Tanzania and West Africa as well. Part II concludes the fascinating history of diamond discoveries on the African continent with discussions of the East African nation of Tanzania and six countries in West Africa. Tanzania is the site of the first economic kimberlite pipe found (in 1940) outside South Africa. Still the world's largest known economic kimberlite, it was discovered south of Lake Victoria. Since 1925, vast alluvial deposits in Ghana and elsewhere in West Africa have yielded large, good-quality alluvial diamonds (figure 1). Also described briefly are several countries in which only sporadic occurrences of diamonds and/or kimberlite pipes have been found, or for which only unsubstantiated accounts have been published (Algeria, Burkina Faso, Cameroon, Congo, Gabon, Kenya, Malawi, Mozambique, Nigeria, Uganda, and Zambia).

Table 1 summarizes diamond discoveries in Africa, including—for each diamond-producing country—the year diamonds (and kimberlites/lamproites) were first discovered, the year of first significant production (100,000 carats), the total production for that country and its percentage of total world production through 1994 (the latest year for which final figures are now available), and its rank in total world production (antiquity through 1994). Note that of the 50-odd countries in Africa today, seven are among the top 10 diamond producers, 25 have recorded diamond occurrences, and 22 have recorded kimberlite/lamproite occurrences.

Part II also looks at early misconceptions about the origin and distribution of diamonds, as well as misinterpretations as to the depth to which diamonds can occur in pipes. It briefly discusses the prevailing modern theory of diamond

Figure 1. The 89.01 ct D-internally flawless Guinea Star was cut from one of the superb large diamonds that have been recovered from alluvial deposits in West Africa. The 255.6 ct piece of rough from which this stone was cut was found at Guinea's Aredor mine in 1986. Courtesy of William Goldberg Diamond Corp.; photo by Shane F. McClure.

formation, and then describes both early and current methods of diamond mining and recovery.

This two-part series concludes with a review of the history of diamond production in Africa. Although reliable figures for annual production by carat weight and by value are sometimes difficult to obtain, an attempt was made to present a synthesis of recorded production figures for all of Africa's major diamond-producing countries. Note that production figures by weight are often marred by inaccurate records and unreliable estimates of illicit production, whereas production figures by value are difficult to relate to present-day values because of monetary inflation; the latter are used in this article only to help compare the quality of diamonds from different deposits. For the most part, the figures given here are based on official reports. Note also that some fluctuations in production may be less a result of shifts in available reserves than a consequence of the desire to balance production and demand worldwide.

HISTORY OF DIAMOND SOURCES IN AFRICA (Continued):

TANZANIA

The first country outside South Africa to have an economic kimberlite pipe, Tanzania (formerly Tanganyika), is also noted for the historically high quality of the modest numbers of diamonds produced there. The discoverer (and, until his death, sole owner) of the Mwadui mine, Canadian geologist John Williamson has a unique place in the lore of the African diamond digger (Gawaine, 1976).

Early Discoveries. Alluvial diamonds were first discovered in 1910 (Kunz, 1911; Gobba, 1989), in the region south of Lake Victoria. In 1925, Tanganyika Diamond and Gold Development Company started small production from eluvial gravels on a kimberlite found at Mabuki, 60 km south of Lake Victoria (Wagner, 1926). Anglo American Corporation evaluated the Mabuki pipe during 1925–1927, but they

TABLE 1. Historical aspects of rough diamond production in Africa from antiquity through 1994 based on official figures (disregarding illicit production).

Country	Year first diamond found[a]	Year first kimberlite found[a]	First year 100,000 carats produced[b]	Total production antiquity–1994 (in millions of carats)[c,d]	Percent (%) total world production[d]	Rank of total world production[d,e]
Algeria	1953[1]	—[2]	—	—	—	—
Angola	1912[3]	1952[4]	1921	66.2	2.5	8
Botswana	1959[5]	1965[6]	1970	214.4	8.2	5
Burkina Faso	1950s[7]	1960s[8]	—	—	—	—
Cameroon	1960[9]	—	—	—	—	—
Central African Republic	1914[10]	—	1947	15.6	0.6	15
Congo	1932[11]	1951?[12]	—	—	—	—
Gabon	1939[13]	1946[14]	—	—	—	—
Ghana	1919[15]	—	1925	102.8	3.9	6
Guinea	1932[16]	1952[17]	1950	10.0	0.4	17
Ivory Coast	1928[18]	1960[19]	1953	5.8	0.2	18
Kenya	?[20]	1968[21]	—	—	—	—
Lesotho	1954[22]	1939[23]	—	0.4	—	22
Liberia	1910[24]	1950[25]	1955	18.5	0.7	14
Malawi	—[26]	1970s?[27]	—	—	—	—
Mali	1955[28]	1956[29]	—	—	—	—
Mozambique	1970s?[30]	1970s?[31]	—	—	—	—
Namibia	1908[32]	1899[33]	1909	68.7	2.6	7
Nigeria	1935[34]	1945?[35]	—	—	—	—
Sierra Leone	1930[36]	1948[37]	1935	54.2	2.1	9
South Africa	1866[38]	1869[39]	1870	485.1	18.5	2
Swaziland	1973[40]	1975[41]	—	0.5	—	21
Tanzania	1910[42]	1925[43]	1945	19.0	0.7	13
Uganda	1938[44]	—	—	—	—	—
Zaire	1903[45]	1908[46]	1917	786.6	30.0	1
Zambia	1960?[47]	1961[48]	—	—	—	—
Zimbabwe	1903[49]	1907[50]	—	0.2	—	23
Total Africa				**1848.0**	**70.4**	
Total World				**2622.3**	**100.0**	
Southern Africa[f]	1866	1869	1870	769.3	29.3	
Central and East Africa[g]	1903	1946	1917	887.4	33.8	
West Africa[h]	1910	1948	1925	191.3	7.3	

[a] *Information from earliest known published references. First kimberlite (or lamproite) is not necessarily the first economic pipe.*
[b] *Data from Levinson et al. (1992), except for Ivory Coast and Liberia (Bardet, 1974).*
[c] *Based on data from Levinson et al. (1992) from antiquity through 1990, and data from* Metals & Minerals Annual Review *(1995) for 1991 through 1994.*
[d] *Total production, percent of total world production, and rank are based on the total weight of rough diamonds produced (without regard to the value).*
[e] *Missing rank numbers are outside Africa, as follows: Australia—3, Brazil—10, China—16, Guyana—19, India—11, Indonesia—20, Russia—4, and Venezuela—12.*
[f] *Southern Africa encompasses: Botswana, Lesotho, Namibia, South Africa, Swaziland, and Zimbabwe.*
[g] *Central and East Africa includes: Angola, Central African Republic, Tanzania, and Zaire.*
[h] *West Africa includes: Ghana, Guinea, Ivory Coast, Liberia, and Sierra Leone (Mali has had no significant production).*

[1] *Kaminskiy et al. (1992); the precise location of a find in the Hoggar area was uncertain (Thebault, 1959).*
[2] *The first reference to the occurrence of lamproitic rocks in Algeria is by Raoult and Velde (1971), but it has not yet been shown that they are the primary host for the alluvial diamonds found near Reggane in southwestern Algeria (Kaminskiy et al., 1992).*
[3] *Legrand, (1984, p 137).*
[4] *Real (1958).*
[5] *Boocock (1960).*
[6] *Boocock (1965).*
[7] *Bardet (1974, p. 21).*
[8] *Bardet (1974); the dunite pipe occurrences (Haut et al., 1984) were discredited recently (Ministry of Mines, pers. comm., 1995).*
[9] *Hartwell and Brett (1962).*
[10] *Middleton (1932).*
[11] *Lebedeff and Choubert (1934).*
[12] *Wilson (1982).*
[13] *Bardet (1974, p. 215).*
[14] *Possible kimberlites were found near Ikoy in 1946 and near Mitzic in 1967 (Choubert, 1946; Bardet, 1974, pp. 218-219).*
[15] *Kitson (1919).*
[16] *Bardet (1974, p. 188).*
[17] *Bardet (1974, p.190).*
[18] *Bardet (1974, p. 206).*
[19] *Knopf (1970); Bardet (1974, p 206).*
[20] *There have been many rumors about diamond finds in Kenya from as early as 1920 (Kunz, 1920) to the present, but none has been confirmed by detailed prospecting.*
[21] *Rombouts (1985); an earlier citation by Rickwood (1969) refers to "central complex kimberlites" (see Mitchell, 1986, p. 24) near Mrima in southeastern Kenya which are carbonatitic dikes.*
[22] *"Colonel Jack Scott . . ." (1978).*
[23] *Stockley (1947) presented the first descriptions of Lesotho kimberlites, but it is not known when they were first discovered.*
[24] *Hatch (1912).*
[25] *Bardet (1974, p. 204).*
[26] *I have not found any reliable reports on the occurrence of diamonds.*
[27] *Bardet (1974, p 53).*
[28] *Bardet (1974, p. 198).*
[29] *Bardet (1974, p. 198).*
[30] *Bardet (1974, p. 53).*
[31] *Bardet (1974, p. 53).*
[32] *Merensky (1909); an earlier find in 1893 near Brukkaros has been discredited (Scheibe, 1906).*
[33] *Scheibe (1906).*
[34] *Junner (1943).*
[35] *McCurry (1973).*
[36] *Pollett (1937).*
[37] *Grantham and Allen (1960); Hall (1970).*
[38] *Robertson (1974).*
[39] *The first Dry Digging discovered was Bultfontein in 1869 (see Janse, 1995, p. 235), but the igneous nature of the pipes was not recognized until 1872 (Cohen, 1872).*
[40] *Hawthorne et al. (1979).*
[41] *Hawthorne et al. (1979).*
[42] *Kunz (1911).*
[43] *Wagner (1926).*
[44] *Barnes (1961).*
[45] *Buttgenbach (1925); see Part I (Janse, 1995, pp. 248-249) for more on the early discoveries.*
[46] *Buttgenbach (1909).*
[47] *I have not found a reference to diamond finds in Zambia before the diamondiferous, but noneconomic, kimberlites were discovered in 1961.*
[48] *Rickwood et al. (1969); Scott Smith et al. (1989).*
[49] *Mennell (1906).*
[50] *Mennell (1908).*

concluded that the results did not warrant a large mining operation. Although other pipes were found in the general area, production from eluvial gravels never amounted to more than 25,000 carats per year until the Mwadui pipe was discovered in 1940 (Edwards and Howkins, 1966).

Discovery of Mwadui. John Thorburn Williamson, a Canadian geologist who came to Africa in 1934, is credited with finding the Mwadui kimberlite pipe on March 6, 1940. The pipe is located about 140 km south of Lake Victoria near Shinyanga, a town about halfway between Lake Victoria and Tabora, the regional capital (figure 2). Williamson had worked for Anglo American a short time. and then for Tanganyika Diamond and Gold Development Company, before he started on his own to look for diamonds in the northwest part of (then) Tanganyika.

After several years of detailed prospecting and frugal living, Williamson found the pipe at the end of a trail of alluvial diamonds he had been following. According to an article in *Indiaqua* ("How Dr. Williamson . . . ," 1974) and recollections by Gerryts (1988), Williamson's chief geologist from 1951 to 1958, Williamson was gently nudged to the area by some Indian traders who had a fair idea of the source of the diamonds because they occasionally bought stones from the local people. An Italian geologist, called Bondini, was also following the alluvial diamond trail, and the traders preferred that Williamson discover the source rather than the Italian, who would become an enemy alien if Italy entered the war on the German side (which it did on June 10, 1940).

Figure 2. The Mwadui pipe, in northwest Tanzania, was the first economic kimberlite discovered outside of South Africa; it is still the world's largest (in area) known economic kimberlite.

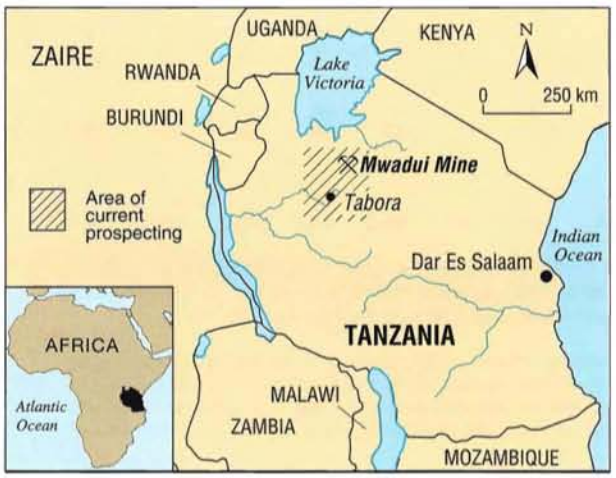


Figure 3. One of the most important diamonds to emerge from Mwadui, the 54 ct Williamson Pink diamond, was found in 1947 and subsequently given to then Princess Elizabeth (now Elizabeth II) of England as a wedding gift. It was cut into a flawless 23.60 ct light pink round brilliant and mounted as the center stone in this brooch. Photo courtesy of the CSO.

Nevertheless, Williamson's discovery was a tremendous feat, which defied conventional wisdom of the era: Until then, economic pipes had been found only in South Africa. (Although diamonds were found in a pipe near Murfreesboro, Arkansas, in 1906, various attempts to mine them from 1907 to 1930 always ended in financial loss.) The Mwadui occurrence is also the world's largest known economic kimberlite. The pipe is topped by a crater up to 1,500 m in diameter, 300 m deep, and 146 ha (361 acres) in surface area (Edwards and Howkins, 1966; Dirlam et al., 1992). Diamonds, including some fine pinks (figure 3), are recovered from surface gravels and crater sediments.

After Williamson died, in 1958, De Beers purchased the mine. Since 1971, it has shared owner-

ship with the government of the newly independent Republic of Tanzania through a Bermuda-based company, Willcroft. Although De Beers prospectors have added hundreds of kimberlite occurrences to those found by Williamson's geologists, the Williamson pipe (now known as Mwadui) is still the only large economic one in Tanzania (Edwards and Howkins, 1966; Gobba, 1989). However, from an annual production that reached more than 500,000 carats in the 1960s (see, e.g., table 2), production has declined to less than 100,000 carats a year currently (table 3). Willcroft's share was recently increased to 75%, and the installations at Mwadui are being overhauled to extend the life of the mine ("Tanzania: De Beers group is to . . . ," 1995).

WEST AFRICA

The first (alluvial) diamonds in West Africa (figure 4) were found in 1910 in the Jiblong River, about 50 km from Monrovia in Liberia (Hatch, 1912). Because of unsettled conditions in that country, they did not attract much attention. The next discovery, in 1919, sparked a large diamond mining operation in the Gold Coast (now Ghana).

Most of the alluvial diamonds found in West Africa were traced to Mesozoic (245 to 66 million years [My] ago) kimberlite pipes and dikes. Mining of the primary host rocks was carried out on a small scale in Sierra Leone, Guinea, and the Ivory Coast during the 1960s, but it was eventually halted because these early ore reserves were depleted or proved inadequate. Thus, virtually all production from West Africa has been derived from alluvial deposits; in all cases except Ghana, these are directly downstream from known primary host rocks.

Ghana (formerly Gold Coast). One of the most important diamond-producing countries in West Africa, Ghana exported up to 3 million carats annually at its peak in the 1960s. Although of good quality, most of Ghana's diamonds are small—less than 2 mm—so they are used predominantly for industrial purposes.

The first alluvial diamonds were found by Albert Kitson, director of the Gold Coast Geological

TABLE 2. Percent of world production by weight for major diamond producing countries and regions in Africa and South America, Russia, and Australia for every tenth year since 1869[a] (and latest data for 1994[b]). Also included are similar percentages for pipe, alluvial, and beach deposits worldwide.

Country	1869	1879	1889	1899	1909	1919	1929	1939	1949	1959	1969	1979	1989	1994
South Africa	15	94	99	98	89	78	48	9	9	11	20	21	9	10
Namibia	0	0	0	0	10	13	8	1	2	3	5	4	1	1
Botswana	0	0	0	0	0	0	0	0	0	0	0	11	16	15
Angola	0	0	0	0	0	2	4	6	6	4	5	2	1	1
Zaire/C.A.R.	0	0	0	0	0	6	25	68	71	56	35	23	21	17
Tanzania	0	0	0	0	0	0	0	0	2	2	2	1	0	0
West Africa	0	0	0	0	0	0	13	14	8	22	14	7	1	2
Total Africa (%)	**15**	**94**	**99**	**98**	**99**	**99**	**98**	**98**	**98**	**98**	**81**	**69**	**49**	**46**
South America	80	5.5	1	2	1	1	2	2	2	2	1	4	1	3
Russia	0	0	0	0	0	0	0	0	0	0	18	27	13	11
Australia	5	0.5	0	0	0	0	0	0	0	0	0	0	37	40
Pipes[c]	0	93	98	96	88	72	30	9	9	11	35	57	77	80
Alluvials[c]	100	7	2	4	2	15	62	90	89	86	60	39	22	18
Beach[c]	0	0	0	0	10	13	8	1	2	3	5	4	1	2
Total World (in millions of carats)	**0.2**	**2.2**	**2.8**	**2.5**	**6.0**	**3.6**	**7.4**	**12.5**	**13.6**	**26.8**	**43.0**	**48.0**	**98.5**	**108.0**

[a] *Percentages calculated from production data for southern Africa for the years 1869 to 1913 in Wagner (1914); for Australia for the years 1851 to 1889 in MacNevin (1977); for South America for the years 1869 to 1913 in author's files; for world from 1914 to 1941 in* The Mineral Industry *(1915-1942); from 1942 to 1965 in* Minerals Yearbook *(1943–1966); for the years 1966 to 1989 in* Mining Annual Review *(1967–1990).*

[b] *Data for 1994 in* Metals & Minerals Annual Review, *1995.*

[c] *Pipes include diamonds recovered from pipes, craters, and overlying eluvial deposits. Alluvials include diamonds recovered from sands and gravels in river beds, terraces, and colluvial deposits on watersheds and slopes. Beach includes deposits in on-shore beaches, tidal zones, and off-shore submarine zones. Percentage distribution for pipes, alluvials, and beach does not correlate with percentages of production from specific countries; for example, South Africa and Zaire produce diamonds from three and two categories, respectively (e.g., production from Zaire for 1989 and 1994 consists of 10% pipe/eluvial material and 90% alluvial).*

TABLE 3. Rough diamond production in 1994 by weight and by value[a].

Country	1994 Annual production by weight			1994 Annual production by value			
	Annual production (in millions of carats)	Percent (%) of annual world production	Rank of annual world production	Average value per carat (in US dollars)	Total value of annual production (in millions of US dollars)	Percent (%) of annual world production	Rank of annual world production
Angola	1.4	1.3	7	187	261.8	4.3	7
Botswana	15.6	14.4	3	90	1,404.0	23.2	1
Central African Republic	0.5	0.5	10/11	175	87.5	1.4	11
Ghana	0.6	0.5	9	20	12.0	0.2	12
Guinea	0.5	0.5	10/11	300	150.0	2.5	9
Ivory Coast	—	—		—	—		
Liberia	—	—		—	—		
Namibia	1.3	1.2	8	290	377.0	6.2	6
Sierra Leone	0.4	0.4	12	270	108.0	1.8	10
South Africa	10.7[b]	9.9	5	113	1,209.1	20.0	3
Swaziland	—	—		—	—		
Tanzania	—	—		—	—		
Zaire	18.0	16.7	2	30	540.0	8.9	4
Zimbabwe	0.2	0.2	13	50	10.0	0.2	13
Total Africa	**49.2**	**45.6**		**84.5**	**4,159.4**	**68.7**	
Australia	43.8	40.5	1	9	394.2	6.5	5
Russia/C.I.S.	11.5	10.6	4	108	1242.0	20.5	2
South America[c]	3.0	2.8	6	70	210	3.5	8
Others	0.5	0.5		100	50.0	0.8	
Total non-Africa	58.8	54.4		32.2	1,896.2	31.3	
Total World	**108.0**	**100.0**		**56.1**	**6,055.6**	**100.0**	

[a]Data for production by weight are from Metals & Minerals Annual Review *(1995). Data for production by value are calculated from data for per-carat value for diamonds from each country in Even-Zohar (1993), except for Zimbabwe, which is from author's files. The one-decimal figures are approximate only, and may generate a false sense of accuracy. Amounts less than 100,000 carats are indicated by dashes.*

[b]Includes an estimated 500,000 carats produced by several fissure mines, off-shore Namaqualand surf and submarine projects, and production from Alexcor (all from author's own files), in addition to the De Beers mines production of 10.2 million carats quoted in Metals & Minerals Annual Review *(1995).*

[c]Includes Brazil, Venezuela, and Guyana.

Survey, while leading a reconnaissance party (on bicycle!) in the Akwatia area of southern Ghana. On February 4, 1919, he and his assistant Edward Teale (later director of the Geological Survey of Tanganyika) crossed the small Abomo Stream, in the headwaters of the Birim River. Some shiny crystals in the stream bank caught Kitson's eye, and they started panning (Kitson, 1919). The few small diamonds they found led to a regional panning survey and further discoveries. Soon, several companies, the most important being Consolidated African Selection Trust (CAST), acquired leases from the local chiefs. CAST started systematic mining in 1925.

After 70 years of mining, from 1924 to 1972 by CAST and thereafter by Ghana Consolidated Diamonds (GCD), the minable reserves at Akwatia are almost depleted. Current production of about 600,000 carats per year actually is generated about half by GCD and half by syndicates of local miners working small, scattered alluvial deposits.

Although Ghana has always produced more diamonds than the other West African countries, for the most part these stones are much smaller than those of its neighbors. Thus, their value per carat has varied between $10 and $20, compared to $270 to $300 per carat for diamonds from Sierra Leone and Guinea (again, see table 3).

Large new reserves have been outlined along the Birim River's middle stretch. These diamonds are slightly smaller, but of better quality (a function of longer alluvial transport), and values per carat of up to $40 have been quoted ("Diamond sales under investigation," 1992). In 1990, Ghana's government invited proposals for the development of these deposits, with strict social requirements for new houses, schools, roads, and the like. A joint venture of Lazare Kaplan International and Inco expressed interest in 1990, but in 1992 Inco withdrew. In 1994, a joint venture of Lazare Kaplan and De Beers studied the feasibility of the project (Stephenson, 1994), but De Beers recently announced that they also have withdrawn. Some companies, including Canada-based Caledonia Mining, have applied for permits to prospect for diamonds in submarine deposits off the Ghana coast.

Only very recently has it been reported that the primary source rock for Ghanaian diamonds has been discovered. It is an altered ultrabasic rock which may represent an altered kimberlite or lamproite (Norman et al., 1996).

Sierra Leone. Since 1935, Sierra Leone has been a producer of large, very good quality, alluvial diamonds (figure 5). It has also become notorious for the illicit digging of diamonds, most of which historically have been smuggled to neighboring Liberia.

The first alluvial diamonds were found in Gboboro Stream in January 1930 by N. R. Junner, director of the Sierra Leone Geological Survey, and his assistant, J. D. Pollett (Pollett, 1937). Gboboro is a tributary of the Bafi River, which flows into the Sewa River, the main trunk river in central Sierra Leone. In March 1931, CAST sent the Dermody brothers, George and Ronald, to prospect further, with encouraging results. From the start, Sierra Leone diamonds were noted for their excellent quality and relatively large size (for example, the 770 ct Woyie River diamond, found in 1945). CAST formed the wholly owned Sierra Leone Selection Trust (SLST) in April 1934, which acquired a diamond-prospecting lease over the entire country. Mining started in 1935, and annual production reached one million carats by 1937, a level that was resumed after World War II.

After years of watching SLST prospectors, local people began to dig for themselves in the early 1950s (Laan, 1965). Since 1955, the high incidence of illegal diamond digging and buying in Sierra Leone, Guinea, and Liberia has caused problems in managing the diamond market. Although such illicit activities have always plagued the diamond industry (in South Africa, laws specifically addressing this problem were promulgated as early as 1882), their impact is particularly severe in regions such as West Africa that have large alluvial occurrences. (Entertaining accounts of diamond smuggling and security counter measures can be found in Fleming [1957], Harbottle [1976], and Kamil [1979]). Designating areas for licensed digging was seen as one way to stop the problem, so the single SLST concession for all of Sierra Leone was replaced in 1955 by two lease areas: Yengema (about 600 km^2) and Tongo (about 210 km^2).

Kimberlite dikes and two small pipes were found in 1948 near Koidu in what is now the Yengema lease, and in 1954 other dikes were found in what became the Tongo lease (Grantham and Allen, 1960). The dikes carried large quantities of diamonds, but they were too narrow for mechanized mining (Hall, 1970).

After 60 years, the once-rich Yengema and Tongo areas are now largely depleted, although some superb large stones have been recovered relatively recently. The National Diamond Mining Company of Sierra Leone (Diminco), which supplanted SLST in 1970, is currently mining small remnants of the previous large terrace deposits and small alluvial deposits scattered throughout the southeastern part of the country. Diamond production in Sierra Leone, which reached an estimated 2 million carats in 1960 (according to official and unofficial sources), currently amounts to about 400,000 carats per year (again see table 3).

Recent prospecting by foreign companies has focused on small high-grade alluvial deposits in the Sewa River (Danielson and Christie, 1993). Several companies, including De Beers, have applied for off-shore diamond prospecting and mining rights between the mouths of the Sewa and Mano rivers ("De Beers returns to Sierra Leone," 1994). In contrast to Namibia, the ocean off Sierra Leone is calm, but the coast and near-shore area is covered in deep mud and mangrove swamps.

Canada-based Diamond Field Resources is studying the feasibility of mining the small (0.4 ha), high-grade (1 ct per tonne) Koidu pipe. Earlier prospecting records indicate that an extraordinary 60% of the diamonds found are gem quality (Danielson and Christie, 1994).

Guinea. Like most of the other West African diamond producers, all of the economic deposits found to date in Guinea are alluvial. A small-scale diamond producer since the mid-1930s, Guinea is particularly noted for the number of large (100+ ct) diamonds found there in recent years (again, see figure 1).

After 1931, the Dermody brothers followed alluvial diamond trails from Sierra Leone into French Guinea (now Guinea). In 1932, they found economic concentrations of alluvial diamonds in the eastern part of the country near Banankoro. The deposits were mined by small Anglo-French joint ventures, notably Soguinex (Société Guinéenne de Recherches et d'Exploitations Minières), in which CAST had a majority holding. Initially, annual production was modest, between 100,000 and 200,000 carats, but illicit mining after World War II pushed the annual figure up to 1.2 million carats in 1957. Swarms of kimberlite dikes and small pipes, discov-

ered in 1952, proved uneconomic. In 1961, the government of the newly independent Republic of Guinea confiscated the assets of all foreign companies, including £1.5 million of diamonds in the mine vault of Soguinex. Soviet geologists invited by the Guinean government found a few more kimberlites, but no large diamond reserves.

By 1981, foreign companies were allowed to return to Guinea. That year, the Association pour la Recherche et l'Exploitation du Diamant et de l'Or (Aredor) was formed—a joint venture with the Guinean government of Australian, Swiss, British, and World Bank interests. Aredor obtained a concession to mine alluvial diamonds downstream from the Banankoro kimberlite field. The Aredor mine, started in 1984, produced some spectacular large, good-quality diamonds. In fact, a diamond over 100 carats was found each year from 1986 to 1990; the largest was 255.6 ct (again, see figure 1). However, overall production was modest, averaging 150,000 carats per year. The mine closed in December 1993 ("Bridge Oil withdraws from Aredor," 1994). Recently, Canada-based Hymex has been seeking venture capital to further develop the mining operation on their alluvial diamond-mining concession in the Diani River, in southeastern Guinea.

Liberia. In the diamond industry, Liberia is known less as a diamond producer and more as a conduit through which diamonds pass from other African nations into the international marketplace. Although Liberia has been prospected extensively since diamonds were first found there in 1910 (Hatch, 1912), for the most part the deposits identified have been too small to entice foreign companies. One exception is Liswimco (Liberian Swiss Mining Corporation), which operated a small mine in the Lofa River area from 1962 to 1968. Australia-based Western Mining Corporation started prospecting operations in 1987, and was granted a mining concession in 1988, but the (still ongoing) civil war halted operations in mid-1990 (Boberg, 1992). Independent diggers have worked many of the small deposits, but it is virtually impossible to estimate this production.

Most of the large quantities of diamonds that Liberia exports annually have been brought illegally from neighboring countries such as Sierra Leone and Guinea historically (Bardet, 1974), and from Zaire since the 1970s. In 1989, Antwerp imported 11 million carats of diamonds that were purported to be from Liberia (Terraconsult unpublished report, 1990).

Figure 4. Numerous diamond deposits have been found throughout West Africa. The major deposits, as indicated here by stripes, are: A—Akwatia/Birim alluvials, Ghana; B—Banankoro alluvials and pipes, Guinea; K—Koidu pipes and dikes, Sierra Leone; Ke—Kéniéba alluvials and pipes, Mali; S—Séguéla alluvials and dikes, Ivory Coast; T—Tortiya alluvials, Ivory Coast.

Ivory Coast (Côte d'Ivoire). The Ivory Coast has historically been a small, intermittent producer of diamonds. Nevertheless, some of the alluvial fields have yielded as much as one million carats total. There has also been limited, but significant, production from dikes in the Séguéla area.

A prospector named Desmons, working for a subsidiary of Forminière (introduced in the Zaire section of Part I, p. 249), found the first alluvial diamonds in 1928, in the Séguéla area. Forminière withdrew because the finds were not encouraging, but the deposits were rediscovered in 1948 by Sandramines (Compagnie Minière du Haut-Sassandra), which started small-scale mining there in 1952. Sodiamci (Société Diamantifère de la Côte d'Ivoire) took over the operation in 1955, and in 1960 they found the origin of the alluvial diamonds, the Toubabouko dike. Although it has been described as a kimberlite (Knopf, 1970), Toubabouko may be a variety of olivine lamproite (Mitchell and Bergman, 1991).

To restrain illicit digging, most of the Sodiamci concession was taken over in 1962 by state-owned Sodemi (Société pour le Développement Minièr de la Côte d'Ivoire). In a joint venture with Waston (itself a joint venture between Harry Winston Inc. and WAST, a subsidiary of CAST), Sodemi further developed Séguéla. Mining continued until 1977, with annual production of about 10,000–20,000 carats. In

contrast to these meager results, it is estimated that independent diggers, mining illegally, actually recovered about one million carats from the Séguéla field in the period 1957–1960 (Bardet, 1974).

In 1963, Gaston Florian of Waston found the Bobi lamproite dike (Knopf, 1970; Mitchell and Bergman, 1991). During 1965–1969, the Waston-Sodemi joint venture recovered about 400,000 carats from the dike and its eluvial deposits (Bardet, 1974).

Alluvial diamonds were first discovered in the Tortiya field during 1935–1937 by prospectors of Minafro (Société d'Exploitations Minières en Afrique Occidentale), which CAST had formed in 1935. Minafro's field party chief was the omnipresent George Dermody, and among his prospectors was the young Marcel Bardet, who later wrote the magnificent three-volume *Géologie du Diamant* (1973, 1974, and 1977). As was the case with Forminière, diamond finds were widespread but not sufficient to outline a promising economic deposit, so Minafro withdrew to Guinea (where it spawned Soguinex). In 1946 a small French company, Saremci (Société Anonyme de Recherches et d'Exploitations Minières en Côte d'Ivoire), used the Minafro data to restart prospecting (again with the help of Marcel Bardet). They traced the diamonds to outcrops of Birrimian sediments containing numerous small diamonds, similar to Ghana's Akwatia deposits (Bardet, 1950). Production started in 1948, and rose to 100,000 carats per year by 1953 and 230,000 carats in 1972, before it started to decline rapidly. Operations ceased in 1975.

Other occurrences of alluvial diamonds and kimberlite/lamproite dikes have been found in northeast Ivory Coast, but little is known about them. Despite widespread prospecting, no large economic diamond deposits have been found in the Ivory Coast since the late 1970s.

Mali. Alluvial diamonds and kimberlite pipes were found near Kéniéba in western Mali in 1955 and 1956, respectively. The discoveries were made by the BRGM (Bureau de Recherches Géologiques et Minières) under the direction of Marcel Bardet and V. Morosoff (Bardet, 1974). The area was investigated by CAST/Selection Trust in the early 1960s, then by a state organization, and finally by Soviet geologists in the 1970s, but no economic deposits were identified.

Currently, the kimberlites and associated alluvial diamond field near Kéniéba are being investigated by Canada-based Mink Mineral Resources ("Mink Mineral Resources Inc., diamonds . . . ," 1993) and Australia-based Ashton Mining.

COUNTRIES WITH MINOR OR UNSUBSTANTIATED OCCURRENCES

Algeria. As in Botswana's Kalahari Desert, large, rich pipes may lie hidden in the Sahara Desert. However, current political conditions and logistical problems have discouraged international companies from pursuing large regional prospecting programs.

The first record of Algerian diamonds dates from 1953 (Thebault, 1959). An early report of a find near Constantine by Dufrénoy (Walferdin, 1834, p. 164) was discredited by Lacroix (1897). In 1990, a team of Algerian geologists, monitored and advised by Russian geologists, found a trail of small alluvial diamonds and indicator minerals in the Bled-al-mas valley of the Sahara Desert (Kaminskiy et al., 1992). This area, which is 50 km west of Reggane in southwestern Algeria, lies on the northeastern margin of the West African craton. Therefore, the diamonds may be derived from as-yet-undiscovered kimberlites located farther northwest in western Algeria, northeastern Mali, or southeastern Morocco, or from lamproites located to the north in Algeria (Raoult and Velde, 1971; Kaminskiy et al., 1992).

Burkina Faso (formerly Upper Volta). Bardet (1974) mentioned alluvial diamond occurrences near the border with the Ivory Coast, but I have found no further information on these deposits. Investigations of aeromagnetic anomalies in the central part of the country started in 1978 and led to the discovery, in 1980, of 23 diamonds in four pipe-like dunite bodies (Haut et al., 1984). More recent investigations determined that these diamonds were probably introduced by contamination in a diamond-processing plant, and the dunites are not individual bodies but part of the steeply folded country rock (Minister of Mines, pers. comm., 1995).

Cameroon. Three diamonds, the largest of which was 1.7 ct, were found in 1960 (Hartwell and Brett, 1962), but no further discoveries have been announced. There are no records of kimberlitic rocks in Cameroon.

Congo. In the 1950s, there was a very small production of diamonds (only a little more than a thousand carats) from a deposit near Komono, which was thought to be a kimberlite (Wilson, 1982). The large

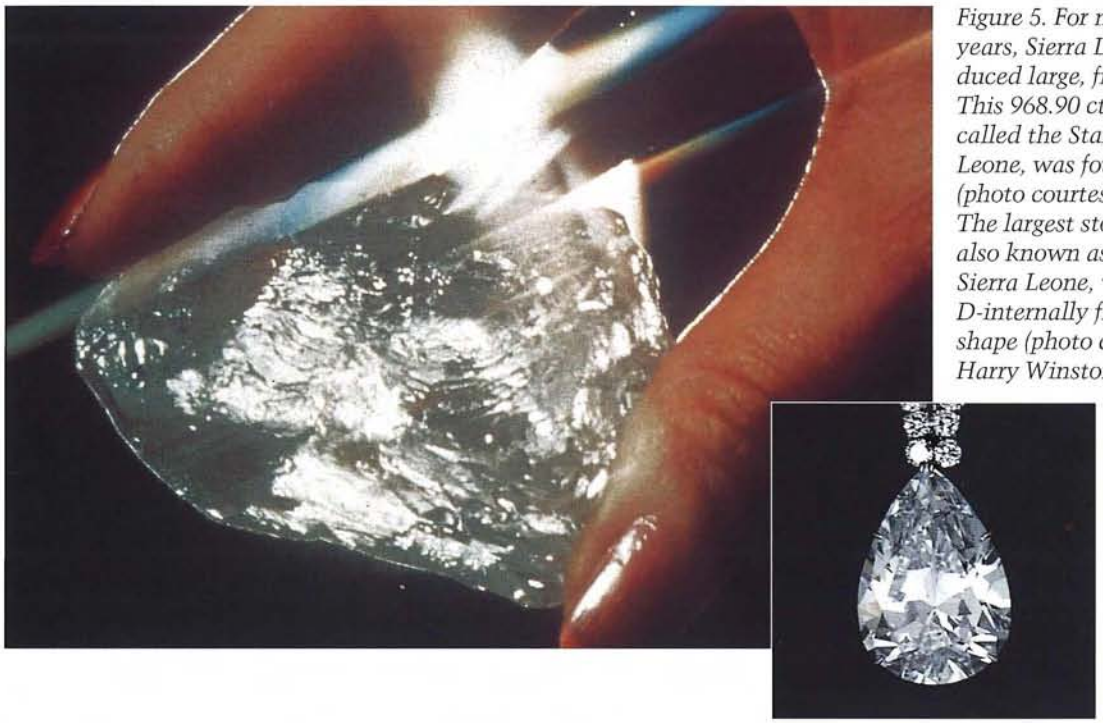


Figure 5. For more than 50 years, Sierra Leone has produced large, fine diamonds. This 968.90 ct piece of rough, called the Star of Sierra Leone, was found in 1972 (photo courtesy of De Beers). The largest stone cut from it, also known as the Star of Sierra Leone, was a 53.96 ct D-internally flawless pear shape (photo courtesy of Harry Winston Inc.).

quantities of diamonds exported from this country in recent years originated from deposits in Zaire.

Gabon. The first alluvial diamonds were found in 1939 in the Waka River valley (Bardet, 1974). Small French companies mined modest quantities of diamonds at several localities, but not enough to establish a local diamond mining industry. Precambrian metamorphosed kimberlites were found in the Ikoy River basin in 1946 (Choubert, 1946) and near Mitzic in 1967, but no diamond mining has resulted (Bardet, 1974).

Kenya. Kunz (1920) reported that a diamond had been found near Nairobi, but this was never confirmed. The present author followed up some alleged diamond finds in 1965, but these, too could not be confirmed or repeated; nor were any diamond indicator minerals found. Rickwood (1969) reported kimberlites in southeastern Kenya, but these occurrences are actually dikes resembling kimberlites, similar to those that often occur around carbonatite complexes worldwide (Mitchell, 1986). The genuine kimberlite just north of Lake Victoria that Rombouts (1985) described is apparently not diamondiferous.

Malawi (formerly Nyassaland). Bardet (1974) reported that a few kimberlite pipes had been found on the west side of the northern part of Lake Malawi. This is directly opposite the Ruhuhu area of Tanzania, on the east side of the lake, where pipes were found in 1956. There are no reliable reports of the occurrence of diamonds in Malawi.

Mozambique. Several kimberlites, at least one of which was diamondiferous, were found near Zumbo in the Tete District of northwestern Mozambique in the early 1970s (Bardet, 1974). No further reliable information is available.

Nigeria. Junner (1943) reported the discovery of three diamonds (one of them 10 ct) 200 km southwest of Kano in 1935, but this was never substantiated. There are no further reliable reports of discoveries, except for an apparently nondiamondiferous kimberlite pipe that was found in the early 1970s (McCurry, 1973).

Uganda. Barnes (1961) mentioned unconfirmed reports of diamond finds made in 1938, but no further published information has come to light. Nor are there any records of kimberlites in this country. However, prospecting in the 1960s produced a few alluvial diamonds in central Uganda (Wilson, 1982).

Zambia (formerly Northern Rhodesia). Prospecting activities in the 1970s and 1980s uncovered many small occurrences of alluvial diamonds in Zambia (confidential reports in author's files), but no deposits large enough to sustain a mechanical operation have been found so far. The first diamondiferous kimberlite, apparently not economic, was found in 1961 (Rickwood et al., 1969), and later prospecting

yielded at least 14 diamondiferous (but not economic) kimberlites (Wilson, 1982). A number of diamondiferous (but not economic) lamproites have also been found (Scott Smith et al., 1989).

THEORIES ON THE GEOLOGY AND ORIGIN OF THE DIAMOND

Integral to the histories of the African diamond sources that have been discussed thus far are corresponding developments in the theories of the geology and origin of diamond, advances in mining technology, and the creation and consolidation of production and marketing channels. In particular, the discovery of the unique diamond source rocks near Kimberley led to an entirely new understanding of the formation of diamond and to new concepts in diamond exploration.

Early Theories about the Nature of the Dry Diggings. The origin and structure of South Africa's dry diggings (Janse, 1995, p. 234) remained a mystery for some time. Most of the dry diggings—except for the De Beers New Rush (Kimberley mine, "Big Hole"), which formed a low hill of about 4 ha (10 acres)—were located in or around pans, that is, shallow depressions. Most of the geologists and land surveyors (usually self-taught geologists as well) who visited the diamond fields included the action of water in their explanations for the origin of the pans, because they were influenced by the nearby alluvial river diggings. Some (Cooper, 1874) suggested that the pans represented depressions filled with detritus deposited by water or ice! The latter must have seemed utterly unbelievable to a hot, dusty, thirsty digger. Even when deeper excavations showed that some of the depressions were surface expressions of the eroded or collapsed tops of steep-sided cylindrical columns (later called pipes), many geologists still invoked action by water and interpreted the columns as mud volcanoes (Morton, 1877). French geologists wrote about *alluvions verticales*, a sort of upwelling of bouldery mud from unknown depth (Meunier, 1877).

Early Mineralogy. At first, the diamonds from the dry diggings were recovered from a yellowish friable calcareous dry mud—*yellowground*—mixed with sand, soil, and rubble at the surface. This porous, easily worked mixture contained, besides mica flakes, hard bright red and black minerals. The latter, respectively called "rubies" and "carbons" by the diggers, are now known as pyrope garnet and magnesian ilmenite (also called picroilmenite; Wagner, 1914). We have also learned that these are the most characteristic minerals in heavy-mineral concentrates from kimberlite and, when found, are usually indicative of the presence of kimberlite (Partridge, 1935). The first to mention the association of red garnets and diamonds is Fred Steytler, who, on a visit to Dutoitspan in October 1869, saw hundreds of garnets and some diamonds in the limey soil of the digging (letter dated November 4, 1869, in Robertson, 1974, p. 219).

The yellowground also contained many fragments of rocks, now called xenoliths (inclusions of rock that are different from the host rock), that were angular (such as sandstone, shale, and diabase, which occur as country rocks in the general area closer to the surface) or subangular (such as granite and quartzite, which were carried up in the pipe from older, deeper rock formations). It also contained rounded fragments composed of two assemblages of minerals that elsewhere in the world only occurred in rocks believed to have formed deep in the Earth's crust: (1) eclogite, consisting of variable proportions of "grass" green clinopyroxene (omphacite) and bright orange-red garnet (Cohen, 1879); and (2) garnet peridotite and garnet pyroxenite, consisting of variable proportions of olivine, clinopyroxene, and garnet, with minor contents of orthopyroxene, ilmenite, and chromite (Wagner, 1914). Occasionally, diamond-bearing eclogites were found; these were first described by Beck (1898) and Bonney (1899).

The rounded rock fragments were called *cognate* xenoliths (different from, but formed *at the same time* as, the rock in which they were enclosed [Wagner, 1914]). At first, they were interpreted as boulders that had formed by the action of water on an old rock formation (Bonney,1899); this theory is consistent with the idea of the dry diggings being depressions filled with some kind of alluvial detritus. Later, the term *cognate* was dropped when it became known that these xenoliths actually formed much earlier than the host rock, and were incorporated during the ascent of the (then magmatic) host, as fragments of the Earth's mantle and deepest parts of the crust (Holmes and Paneth, 1936).

First Scare: Yellowground Running Out. In 1872, at about 17 to 27 m (55 to 90 feet) depth in the Kimberley or the De Beers mine (it is not known which mine was first), diggers found that a much harder, compact, bluish gray rock (i.e., *blueground*)

underlay the yellowground. Many sold their claims because they thought that they had reached the bottom of the depression and thus the end of the diamondiferous ore (Williams, 1905). Those diggers who kept going deeper—perhaps out of desperation, but more likely because the transition from yellowground to blueground is gradual and there is no sharp break—were amazed and pleased to continue to find diamonds (Williams, 1905).

At first, diggers had difficulty recovering diamonds from blueground, because it had to be broken up by pounding. Then they found that most blueground weathers easily on exposure to surface conditions, especially when wetted. This led to new diamond-recovery methods: The diggers spread broken blueground on the surface in so-called "floors" and left it to weather for six to nine months, at which point most of the rock fell apart easily and could be sieved to recover the diamonds. The blueground that would not disintegrate, but rather stayed hard, was called *hardebank*.

Second Scare: No Diamonds below the Carbon Shale Horizon. The next scare arose from the theory that the diamonds were formed by the action of a hot basic magma on a formation of carbon-rich shale that occurs in the wallrock of the pipes around Kimberley (Dunn, 1881). Thus, there would be no diamonds in the pipe below the carbon-shale horizon, which occurred at a depth of 75 m (245 feet).

The scare subsided in the mid-1880s, when diamonds were found in blueground below the shale horizon. The carbon-rich shale theory was finally laid to rest in 1903, when the large Premier pipe was discovered about 500 km (320 miles) northeast of Kimberley: The kimberlite-penetrated rocks in this highly diamondiferous pipe were much older than any carbon-rich shale horizons formed in South Africa, so the kimberlite could not have broken through any carbon-shale horizon. A similar observation had been made by government geologist Molengraaff (1897) in his report on the first small pipe (the diamondiferous, but not economic, Schuller pipe) discovered in the Pretoria district, but it was largely ignored at the time.

Recognition of the Volcanic Nature of the Pipes. German mineralogist Emil Cohen (in 1872) was the first scientist to state in print that the dry diggings were actually steep-sided cylindrical columns that represented volcanic conduits. Cohen wrote about pipes of eruptive tuff in which the diamonds are embedded, from which it can be deduced that he thought that the diamonds were brought up from below by volcanic action and were not deposited in depressions by rivers. In 1879, Cohen first noted that some of the so-called cognate xenoliths were very similar to certain small bodies of high-grade metamorphic rock found in southern Germany that were called eclogites. Cohen was also the first (in 1877) to discover by chemical analyses that the black minerals the diggers called "carbons" were ilmenite with a significant magnesium content (10%–12% MgO), and (in 1889) to determine that the red garnets they called "rubies" were chrome-bearing magnesian garnets called pyrope.

(British-born) Australian geologist E. J. Dunn (1874) first introduced the term *pipes* in print. At that time, he was with the Geological Survey of the Cape Colony. He is usually credited with being the first to recognize the igneous origin of this peculiar kind of rock, which he described as a breccia in a matrix of gabbro (an igneous rock consisting of pyroxene and feldspar). Cohen (1874) later wrote that *he* was the first scientist to recognize the igneous nature of the dry diggings, in his 1872 paper. However, because all of his publications were in German, he attracted little attention.

Gradually it became clear that the pipes at Kimberley contained a previously unknown type of ultrabasic rock, and several names were suggested, such as "adamasite" for the rocks around Kimberley (Meunier, 1882) and "orangite" for the more micaceous variety in the Orange Free State (Wagner, 1928). The name *kimberlite* was proposed for the first time in an 1887 lecture at a meeting of the British Association for the Advancement of Science in Manchester, England, by American mineralogist Henry Carvill Lewis, of the Academy of Natural Sciences in Philadelphia (Lewis, 1888). Although Lewis never visited the diamond fields, he did microscopic examinations on rocks sent to him. Before he could publish the results of his studies, Lewis died of typhus late in 1888. His papers were handed first to George H. Williams, professor of mineralogy at Johns Hopkins University in Baltimore, Maryland, but he also died of typhus. Lewis's widow then gave the papers to Thomas G. Bonney, of University College, London, and almost 10 years after Lewis's death his ideas and investigations were published (Lewis, 1897). With this publication, the term *kimberlite* started to be used by geologists; it gained widespread acceptance after the publication of Wagner's landmark 1914 book.

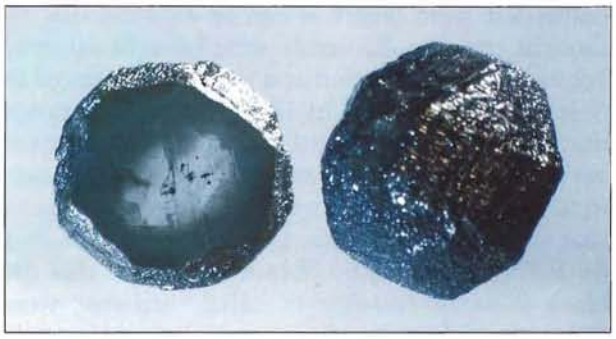


Figure 6. Coated diamonds—stones with green or rough skins over transparent interiors—are common in Sierra Leone and the Mbuji-Mayi region of Zaire. A window has been cut on one of these approximately 5-mm-diameter diamonds to show the color and clarity of the interior. Photo courtesy of Dearn Lee, Ashton Mining.

Diamonds Recognized as Xenocrysts in Kimberlite. In the early days of the wet (river) and dry (pipe) diggings, an obvious difference in the quality of diamonds recovered from the two types of deposits was observed. Almost immediately, the term *River stones* emerged to signify the better quality of the alluvial diamonds. The overall production at the De Beers Rush (De Beers mine) and De Beers New Rush (Kimberley mine) had a faintly yellowish tinge, but to avoid the word *yellow*, the first public relations man in the field thought to use *Cape* or *Cape White*. When diamonds from Wesselton and Jagersfontein arrived on the market, the terms *Wesselton* and *Jagers* came into being to indicate their superior quality over stones from other pipes. In a more regional sense, certain areas have their own characteristic stones, such as *Cubes* (cube-shaped stones) from Mbuji-Mayi (Zaire), *Carbons* (bort) from the Central African Republic, and *Coated stones*, which are common in both Sierra Leone and Mbuji-Mayi (figure 6).

Experienced diggers and sorters claimed that they could identify the pipe from which a diamond came, because each pipe had its own characteristic mix of sizes, shapes (crystal forms), colors, and surface markings (Williams, 1932). Because of these differences, early theories on the origin of diamond in South Africa maintained that the diamonds had grown in the magma within each pipe (Dunn, 1881; Lewis, 1897); thus, they should be regarded as phenocrysts (crystals that form early in a magma).

Others believed that the diamonds as well as the cognate xenoliths, eclogites (some of which contain diamonds), and garnet peridotites had formed in the original magma before eruption and were subsequently transported to the surface, where the rest of the magma solidified (Williams, 1932). Thus, the diamonds could still be regarded as phenocrysts and the xenoliths as cognate—that is, formed from the same magma at the same time—but it was not known how long they had formed before the pipe erupted.

Bonney (1899) proposed that the diamond-containing eclogites were formed much earlier (he could not say how much) than the kimberlite magma and thus were not cognate. He thought that diamonds in kimberlite originated from the breakup of eclogites, presumably caused by the eruption of the pipe. Holmes and Paneth (1936) were the first to measure the age of formation of the eclogites; they obtained Precambrian ages (older than 1,000 My) for eclogites in South African kimberlites that had intruded rocks of Mesozoic age (about 100 My).

Although the age of formation of diamond itself cannot be measured, that of certain minerals included in diamond, such as sulphides and garnets (figure 7), can be. Kramers (1979) carried out the first measurements on sulphide inclusions, and Richardson et al. (1984) did the first age dating on garnet inclusions. The results showed that most diamonds were formed eons earlier than the kimberlite in which they occur—that is, they are true xenocrysts. It is wonderful to realize that when you hold a diamond in your hand you hold an object that is from 1,000 to 3,300 million years old! (Diamonds as young as 628 My are known, but they are rare [Kinny and Meyer, 1994].)

Modern theories on the origin of diamonds and their transport in kimberlites and lamproites can be found in Mitchell (1986), Gurney (1989), Kirkley et al. (1991), and Haggerty (1994). The central theme of these new theories is that diamonds formed at depths of 150–200 km in the upper mantle as much as 3,300 My ago. They were located in regions where the mantle was cooler (and thus solid) rather than hotter (and fluid). If these areas remained cool and essentially unchanged for long periods of time (as evidenced by the occurrence of Archaean rocks [older than 2,500 My] or in some cases Proterozoic rocks [older than 1,600 My on the surface]), they could be penetrated by deep-seated igneous magmas that would then transport the diamonds to the surface. The rocks formed from these magmas, such as kimberlites and lamproites,

would be much younger (1,600 to 50 My) than the diamonds or their original hosts.

Distribution of Diamondiferous Kimberlites on Cratons. Clifford's Rule (Clifford, 1966) states that the most favorable environment for the intrusion of kimberlite pipes is a craton (an ancient, stable, and rigid part of the Earth's crust). Worldwide observation has shown that *economic* kimberlites occur only on archons, that is, those parts of cratons that are underlain by basement rocks of Archaean age (more than 2,500 My old), whereas economic lamproites may also occur on protons (parts of cratons underlain by basement rocks of Early Proterozoic age, between 2,500 and 1,600 My old) close to the margin of archons (Janse, 1994).

The distribution of Archean cratons in Africa is shown in figure 8, and the geology of diamond and kimberlite/lamproite occurrences in Africa and worldwide is summarized in Janse and Sheahan (1995). Most economic kimberlites (all the large pipe mines) known at present on the African continent occur in the Kalahari archon of South Africa and Botswana, which is part of the South African craton. This may be due not only to its geology and structure, but also to the fact that the South African craton is fairly well inhabited and logistically the easiest to explore. From a geologic/structural viewpoint, other economic kimberlite pipes can also be expected to be found in Archean cratons that are more difficult to explore, such as the West African craton, a large part of which is covered by the Sahara Desert.

Primary Diamond Host Rocks. Primary diamond host rocks include kimberlite, lamproite, and—rarely—ultrabasic or alkaline lamprophyres (rocks containing large, dark-colored minerals, including olivine, dark mica, pyroxene, and amphibole, set in a fine-grained groundmass). However, only a few primary host rocks form economic diamond deposits. Of an estimated 5,000 worldwide occurrences of kimberlites and lamproites, only 50-odd kimberlites have been mined. Only 25 of these produced significant quantities of diamonds, and only 15 major kimberlite pipe mines are active at present (Sheahan and Janse, 1994; Rombouts, 1995). Six lamproites have produced significant quantities of diamonds, and one—Argyle in Western Australia—is the world's largest diamond mine (in carats per year) at present. On the African continent, almost all economic primary diamond deposits were developed on kimberlites; only one small, now-dormant mine (Bobi) in the Ivory Coast near Séguéla was developed on lamproite dikes. Thus far, no economic deposits have been developed on ultrabasic or alkaline lamprophyres, anywhere, although diamonds have been found in these rocks.

Figure 7. Garnet is an important diamond indicator mineral, having crystallized in a similar high pressure/moderate temperature environment in the mantle. The garnet shown here is included in a 2 ct diamond. Photo courtesy of Craig Smith; from the John J. Gurney collection.

Prediction of Diamond Potential. It gradually became widely known that the presence of garnet and ilmenite in alluvial samples or in soil was a useful indication that diamonds might also occur. The range of indicator minerals was subsequently broadened to include diopside and chromite. Because all these minerals are common in many different rock types, the recognition of the specific varieties that accompany diamonds requires great skill in practical mineralogy. At first, this was done by observing the color (deep red to purplish red for chromiferous garnets, "emerald" green for chromiferous diopside) and the shape and surface markings (for ilmenite). In the 1950s, measurement of the refractive index, unit-cell size, and specific gravity of single grains became diagnostic; in general, the lower the value for each of these properties is, the more likely it is that the source is kimberlitic (when these minerals occur in more common igneous rocks, their values for these properties are typically higher).

In the 1970s, the electron microprobe made it possible to analyze single small grains for their

major-element content, which led to the development of classification schemes for garnet, ilmenite, and chromite—based on their mineral chemistry—that claimed to predict whether the host rocks being traced were diamondiferous or not. These methods were first investigated by Sobolev and co-workers in Siberia (Sobolev et al., 1973); they were separately developed in South Africa and Botswana and commercially applied by Gurney and Switzer (1973) and Gurney (1985).

Finally, in the late 1980s, the proton microprobe and the laser probe made it possible to determine the trace-element content of single small grains. This led to the "thermometers" for garnet and chromite developed by Griffin et al. (1989). They claimed that from the content of trace elements such as nickel in garnet, the temperature of formation can be calculated. When a high proportion of the measured garnets fall within the temperature range in which diamond is formed, then the potential for diamond is high. As a result, prospecting has evolved from a relatively simple sampling survey to a highly sophisticated exercise in mineral chemistry. However, samples still have to be methodically collected in the correct locations by skilled, reliable prospectors.

DIAMOND MINING AND RECOVERY

Early Mining Methods. The mining of diamondiferous material involves three major steps: (1) digging up gravel, soil, or rock; (2) washing and sieving the gravel, soil, or rock to remove undersize (mud) and oversize (lumps of rock) materials; and (3) recovering diamonds from the washed material. In early diamond mining, the three steps were carried out in one continuous process. In fact, this rudimentary procedure is still used today by indigenous people working as individuals or in small groups in Angola and Central and West Africa, using simple shovels for digging, handheld wire-mesh sieves for washing (figure 9), and picking the diamonds out by hand. This workforce is known as artisanal labor.

Within a few years of the first diamond discoveries in South Africa, several people with experience in Australian or Californian alluvial gold workings came to the South African diamond fields. This resulted in improvements at every step to increase the volume of material treated and the efficiency of diamond recovery. More and more capital was required, claims were combined, and individual diggers formed small group syndicates. The syndicates eventually made way for joint stock companies, which raised capital on the international money market.

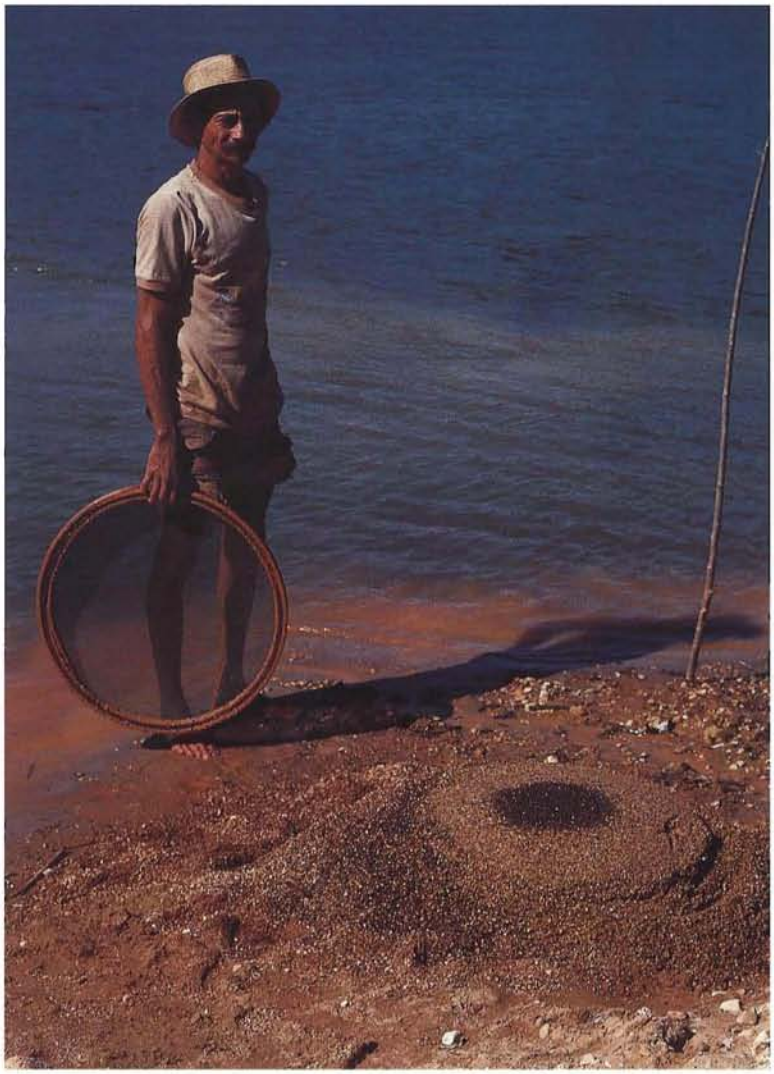


Figure 9. Simple hand gravitator sieves are still used in many parts of Africa to look for diamonds. Note the "dark eye" of heavy minerals in the center of the gravels. Photo by A. J. A. Janse.

Mechanization in the Recovery of Diamond. At first, from 1871 to 1873, the friable yellowground from the dry diggings was processed without water (dry sorting) by the use of the "baby," a rocking cradle of screens. However, the more compact blue ground had to be pulverized or left on "floors" to weather and then treated with water in cradle-ripple washers ("long toms"). The "rotary pan washer" and "trommels" were introduced in 1875, and various jigs and finally the "pulsator" (1898) were used to concen-

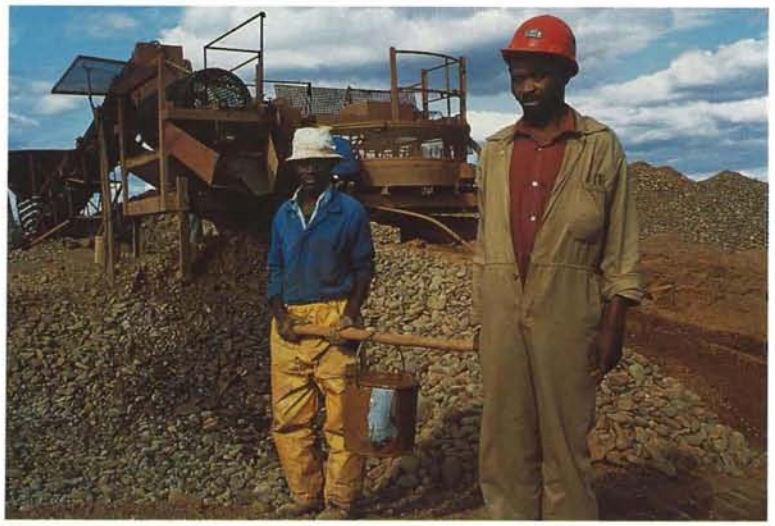


Figure 10. Simple trommels and jigs are still used today to process the ore at small aluvial mines such as this one in South Africa. Photo courtesy of Robert E. Kane.

trate the material further. The recovery of diamonds from the washed and concentrated material became more efficient with the invention of grease tables and grease belts in 1896 and 1910, respectively. Detailed descriptions of all these methods can be found in Reunert (1893), Wagner (1914), and Bruton (1978). Many of the tools (rotary pans, trommels, jigs, grease belts, etc.) are still used today at alluvial and small pipe mines (figure 10).

In modern times, concentration has also been carried out by means of heavy-media separators (cones filled with a slurry of fine ferro-silicon powder). These machines have been used at mines since 1950 and in mobile units since the mid-1970s. Small diamonds have been recovered by electrostatic methods since 1947. Currently (since 1958 in Siberia and since the mid-1960s elsewhere), the most efficient and secure method of recovering diamonds is by X-ray separation in Sortex machines. Details of these methods can be found in Linari-Linholm (1969) and Bruton (1978). Processing plants at the newest large mines often extend over several acres (figure 11).

Underground Mining. Traditional methods of underground mining for base metals and gold were modified to accommodate vertical pipe-like bodies, and new methods were developed. The earliest—drift stoping—methods were both haphazard and dangerous. They were replaced around 1890 by the "chambering" method, by which several large caves (chambers) were excavated in several levels vertically above one another with wide pillars between them. Gardner Williams, the first technical manager of De Beers Mining and its general manager from 1887 to 1905, developed this method (Williams, 1905). Detailed descriptions can be found in Williams (1911) and Wagner (1914). The chambering method was replaced around 1958 by "block caving," in which large caves slowly collapse and the blocky ore is withdrawn from only one level. This method is better suited to mechanization and is more economical (Bruton, 1978).

HISTORY OF DIAMOND PRODUCTION

Early Stages. Before 1869, all the world's diamonds were derived from alluvial deposits; 90% of the estimated 200,000 carats produced annually came from Brazil, and the remainder came from India, Borneo, and New South Wales, Australia. This changed in 1869, when the alluvial diamonds from the Cape Colony came on the market (see table 2), and by 1870 South African alluvials accounted for 15% of the world's diamonds. The most dramatic change was caused by the opening up of the "dry diggings." Diamond production from South Africa amounted to 102,500 carats in 1870 and 269,000 carats in 1871, when stones were recovered primarily from alluvial deposits; in 1872, when miners started working the dry diggings, production suddenly rose to 1.08 million carats (Reunert, 1893). The impact of pipe-mine production is evident in the jump from 0% of total world production in 1869 to 93% in 1879 (table 2).

The First Thirty Years (1871–1900): The Emergence of De Beers Consolidated Mines and Dominance of Pipe Mines. *Pipe-Mine Production.* By the end of this period, the South African pipe mines generated 96% of world diamond production, with the remaining 4% distributed about equally between the alluvial deposits along the Vaal River in the Cape Colony and Transvaal, and the alluvial deposits in Brazil. The number of stones mined declined slightly in 1882/1883, when prices dropped in response to overproduction, but a peak of 3.7 million carats was reached in 1888, just before De Beers Diamond Mining Company consolidated all the claim blocks in the De Beers and Kimberley mines into De Beers Consolidated Mines Ltd. De Beers also gradually purchased a majority shareholding in the companies that controlled all the other large diamondiferous kimber-

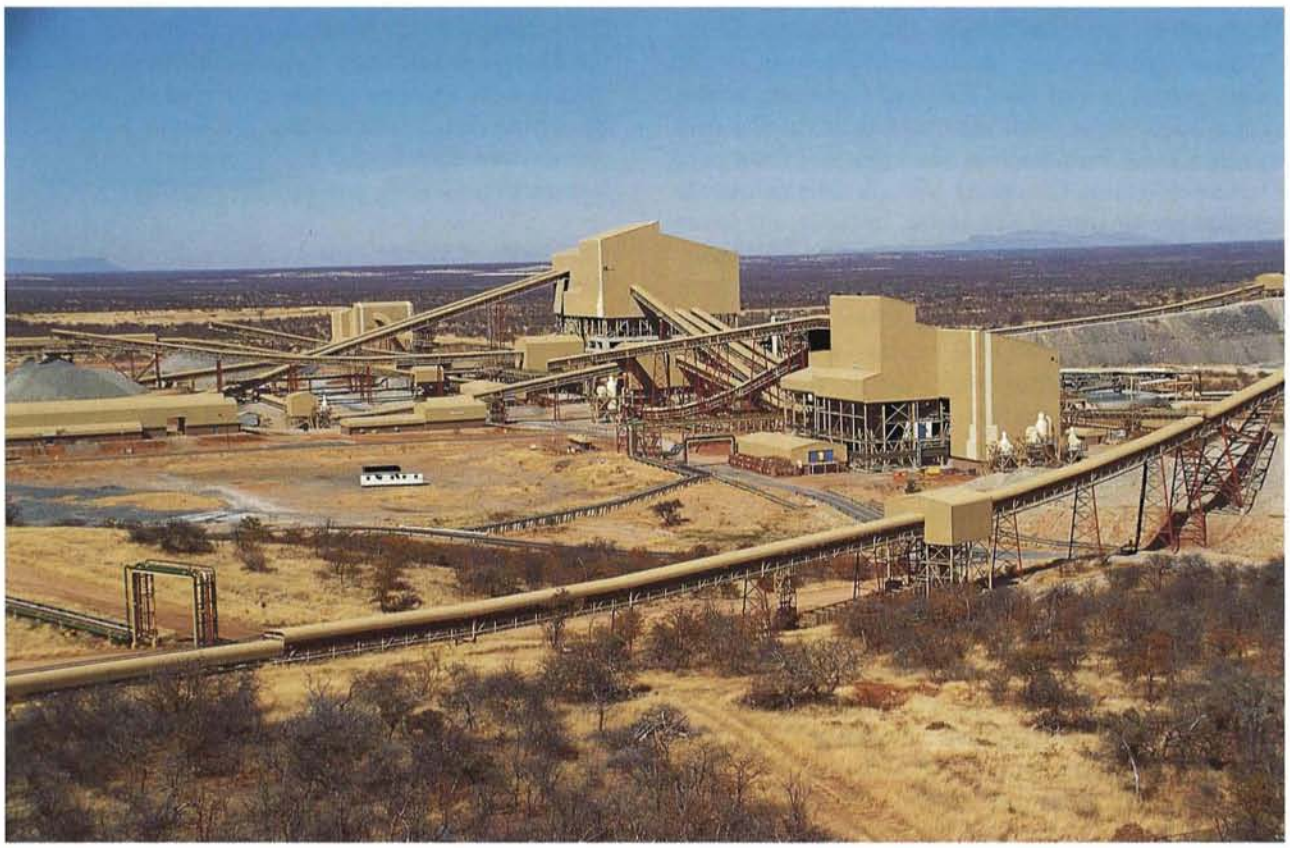
lite pipes—the Bultfontein, Dutoitspan, and Wesselton mines in the Kimberley area, and the Jagersfontein and Koffiefontein mines in the Orange Free State—and leased the production rights. So, from 1888 to 1900, De Beers produced nearly all the world's diamonds.

Estimates are that in the early stages, when yellowground was mined, the grade at the Kimberley mine was well over 2 carats per metric tonne (ct/t); at the De Beers, over 1.5 ct/t; at Bultfontein, about 0.58 ct/t; at Dutoitspan, about 0.32 ct/t; and at Jagersfontein, about 0.1 ct/t (Reunert, 1893). In later mining operations, there was a general decrease in grade, but the head grade (the grade derived from the actual recovery of diamonds at the processing plant) increased at some stages as miners penetrated the blueground. This has been attributed to the existence of different types of kimberlite, but it is more likely the result of improved recovery methods (Sutton, 1918). In 1890, the grade at the Kimberley mine—then at a depth of about 240 m (800 feet)—was still 2.14 ct/t; it had decreased to 0.4 ct/t by the time the mine was closed in 1914 ("Sampling diamond mines," 1956), and it averaged just above 1 ct/t over its active life (for current grades, see table 4).

By about 1900, many other kimberlite pipes had been discovered in South Africa, but these either were not diamondiferous or were low in tenor or small in volume. Furthermore, it appeared that the closer the pipes were to Kimberley, the bigger and better they were, so Kimberley was considered the world's center of large, economic kimberlite pipe mines. This was expressed by Cecil Rhodes in his presidential address to the Eighth Annual General Meeting of De Beers Consolidated Mines (*De Beers Annual Report* for 1896). The September 1890 discovery of the large, economic Wesselton pipe less than 8 km (5 miles) from Kimberley seemed to confirm this viewpoint.

The First London Diamond Buying Syndicate—the Breitmeyer Syndicate. The drastic drop in diamond prices in 1882/1883 favored the consolidation of

Figure 11. At South Africa's Venetia mine, which officially opened in August 1992, a modern processing plant occupies a broad area next to the open-pit mining operation. Photo courtesy of De Beers.



claims and small companies. To regulate and stabilize the supply and price of diamonds, the London Diamond Buying Syndicate (often called simply the "Syndicate") was formed in 1889. It contracted to purchase all the diamonds produced by De Beers. The Diamond Syndicate originally consisted of four firms: Barnato Brothers, Dunkelsbühler & Co., Mosenthal and Sons, and Wernher, Beit & Co. This first Syndicate was later called the Breitmeyer Syndicate, after L. Breitmeyer, who was Wernher, Beit & Co.'s agent in London; it lasted until 1926. (For a detailed discussion of the Syndicate, see Newbury, 1989.)

Production Levels. From 1889 onward, following the formation of De Beers Consolidated Mines Ltd., more-reliable records for diamond production exist. During the period 1889–1900, annual production averaged 2 million tonnes of ore, resulting in 2.4 million carats at a grade of 1.2 ct/t. There was a slight setback in production during the Boer War, but the five Kimberley-area mines survived the siege of Kimberley more or less undamaged, and production resumed at once after the siege was lifted.

The Second Thirty Years 1901–1930: Challenges to the Regulated Diamond Market by Widespread Discoveries. *First Challenge—the Discovery of the Premier Pipe.* The first challenge to De Beers as the major producer and the Diamond Syndicate as the major buyer came with the opening of the Premier mine in 1903, inasmuch as the Premier (Transvaal) Diamond Mining Company sold all their diamonds outside the Diamond Syndicate. Initially, De Beers did not believe that the mine would be an important producer, but it was soon persuaded when, in its first full year of operation (1904), the Premier produced almost 750,000 carats—a figure that increased rapidly thereafter. De Beers and their associates, such as Barnato Brothers, responded by gradually purchasing more and more Premier shares and trying to persuade the Premier management to come to a quota agreement (to limit production at each mine to a certain percentage of total [world, at that time] production) with the Diamond Syndicate, but the management of the Premier mine responded only reluctantly.

In September 1907, a financial crisis in the United States reduced the projected demand for diamonds the following year. De Beers responded by reducing output from their mines. In 1908, they closed the De Beers (only re-opened in 1963) and Dutoitspan (re-opened in 1910) mines (see table 5). The Premier mine's managers broke the tentative agreement that they had reached with the Diamond Syndicate and continued production at a high level, thereby in 1908 slightly exceeding De Beers's production. By 1911, however, Barnato Brothers had purchased a controlling interest (at least 20%) of the Premier company. Premier subsequently joined the Diamond Syndicate's quota system, which was agreed to in July 1914 in cooperation with the Diamant Regie (see next section). That same year, Ernest Oppenheimer formed the Anglo American Corporation of South Africa ("Anglo American") to raise venture capital for the gold mines of the Rand, near Johannesburg.

Second Challenge—the Discovery of the Coastal Deposits in German South West Africa (now Namibia). The second challenge to De Beers's and South Africa's leading position in world diamond production came in 1908, when diamonds were found in beach and dune sand in German South West Africa. The beach sand mines started production (of small, good-quality diamonds) in 1908, and by 1909 they had captured 10% of the world market (table 2).

De Beers responded by persuading the Diamant Regie (the German organization in charge of selling the German South West Africa diamonds) to join the Diamond Syndicate's single-channel marketing system. An agreement was achieved in July 1914 by which the quota for the De Beers Kimberley mines was 48.5%, for the Premier—19.5%, for Jagersfontein—11%, and for Diamant Regie—21%.

Outbreak of World War I. The outbreak of World War I the month after the quota agreement was signed reduced demand for luxury goods, including diamonds, while it accelerated the demand for manpower to fight the war (many of the miners volunteered). De Beers responded by closing their mines in July and August of 1914, and the Premier Company followed suit. Although the Kimberley mine (the Big Hole) stayed closed forever, most of the other Kimberley mines and the Premier resumed production between January and July, 1916 (table 5). The Premier mine never reached its pre-war annual production levels of over 2 million cts, but stayed below one million carats until the mine was closed again in March 1932.

After its troops occupied South West Africa in the first half of 1915, the South African government took control of diamond mining there. When the war ended, the German diamond mining prop-

erties were acquired by Consolidated Diamond Mines of South West Africa (CDM), which Ernest Oppenheimer formed in 1919 specifically to purchase and develop the mines in the former German territory. In January 1920, the quota system agreed to in 1914 was renewed for a five-year period, and Anglo American joined the Diamond Syndicate.

Recession of 1921/22. A general recession and a glut of cut diamonds from Russia (confiscated from the estates of emigrés by the new Communist government, or offered by the emigrés themselves) lowered the demand for new production in 1921 and 1922. De Beers again responded by reducing output: It closed the three operating (Bultfontein, Dutoitspan, and Wesselton) Kimberley mines and the Jagersfontein and Koffiefontein mines in early 1921 (table 5), and it reduced output at the Premier mine to about 300,000 carats in 1922. Total production from South Africa dropped to as low as 670,000 carats in 1922. Total world production was only just over 1.3 million carats, most of which came from new alluvial mines in the Belgian Congo (now Zaire) and Angola. Anglo American, by acquiring large shareholdings in these mines, secured contracts to purchase all their output, so these diamonds also flowed through the Diamond Syndicate.

Third Challenge—the Discovery of the Lichtenburg and Namaqualand Coast Alluvial Deposits and the Rapid Increase in Alluvial Production Outside South Africa. The pipe mines were reopened gradu-

TABLE 4. Area, grade of kimberlite ore, value of diamonds per carat, and value of kimberlite ore per tonne, plus calculated volume of kimberlite ore to 120 m, quantity of diamonds to 120 m, and total value of diamonds to 120 m, for selected African diamond pipes.

Pipe	Country	1 Area of pipe (in ha)[a]	2 Grade of kimberlite ore (carat per tonne)[a]	3 Value of diamonds per carat (US$)[b]	4 Value of kimberlite ore per tonne (US$)[c]	5 Volume of kimberlite ore to 120 m (millions of tonnes)[d]	6 Quantity of diamonds to 120 m (millions of carats)[e]	7 Total value of diamonds to 120 m (millions of US$)[f]
Bultfontein	South Africa	9.7	0.40	75	30	24	10	750
Camutue	Angola	9.3	0.12	200	24	23	3	600
Catoca	Angola	66.2	0.46	60	28	65	30	1,800
De Beers	South Africa	5.1	0.20[g]	80	16	12	2	160
Dokolwayo	Swaziland	2.8	0.27	100	27	7	2	200
Dutoitspan	South Africa	10.6	0.20	75	15	26	5	375
Finsch	South Africa	17.9	0.75	40	30	44	33	1,320
Jagersfontein	South Africa	10.1	0.07	200	14	25	2	400
Jwaneng	Botswana	54	1.37	110	150	136	186	20,460
Kimberley	South Africa	3.7	1.00[h]	110	110	9	9	990
Koffiefontein	South Africa	10.3	0.08	125	10	25	2	250
Koidu	Sierra Leone	0.4	1.00	200	200	1	1	200
Letlhakane 1	Botswana	11.6	0.38	120	46	29	11	1,320
Letlhakane 2	Botswana	3.6	0.26	120	31	8	2	240
Letseng	Lesotho	15.9	0.04	400	16	9	0.4	160
Mwadui	Tanzania	146	0.20	85	17	143	29	2,465
Orapa	Botswana	106.6	0.68	50	34	104	71	3,550
Premier	South Africa	32.2	0.48	70	34	82	39	2,730
Tshibua 1	Zaire	18.6	3.00	10	30	18	54	540
Venetia	South Africa	12.7	1.28	80	102	32	41	3,280
Wesselton	South Africa	8.7	0.24	100	24	21	5	500

[a] *Values for area of pipes, and grade of kimberlite ore, modified from Janse (1993), Jennings (1995), and* De Beers Annual Reports. *All grade and value (see footnotes "b," "c," and "f" below) figures are approximate and may vary from year to year as different types of ore are mined. The Letseng calculations used 3.7 ha (see Janse, 1995, p. 243). Conversions: 1 hectare (ha)= 2.47 acres. 1 metric tonne (the unit of weight used in diamond mining) = 2204.6 pounds or 1.102 short tons.*

[b] *Value of diamonds per carat from Even-Zohar (1993), Rombouts (1994), and author's files.*

[c] *Value of kimberlite ore per tonne modified from Janse (1993) or Jennings (1995).*

[d] *Volume of kimberlite ore calculated from the surface area of the pipes and assuming the pipes taper at angles of 82°; except for Catoca, Mwadui, Orapa, and Tshibua 1, which are treated as cones tapering at 45°. Conversion of cubic meters to tonnes: 1 m^3 = 2.2 tonnes. Note: Depths are calculated to 120 m, as this is the depth to which open-pit mining is usually possible.*

[e] *To obtain "Quantity of diamonds to 120 m," multiply Column 2 by Column 5. Figures are approximate.*

[f] *To obtain "Total value of diamonds to 120 m," multiply Column 3 by Column 6.*

[g] *Average grade from 1963 to 1980 (Clement, 1982).*

[h] *Average grade from 1890 to 1913 ("Sampling diamond mines," 1956).*

TABLE 5. Periods of main activity of the major diamond pipes of South Africa and Botswana[a].

Mine	Discovered	Start of production	Start of underground mining	Main periods of closure and date of final closure when applicable	Remarks
Bultfontein	September 1869	1869	1906–1910	August 1914–January 1916 March 1921–August 1924 March 1932–June 1937 December 1939–October 1944 July 1949–December 1952 September 1971–June 1974	Still active.
Dutoitspan	October 1869	1869	1906–1910	January 1908–January 1910 August 1914–May 1916 March 1921–December 1925 July 1931–March 1936 December 1939–September 1943 March 1947–July 1949 November 1952–June 1955	Still active.
Jagersfontein	July 1870	1870	1910–1914	August 1914–January 1916 January 1921–November 1922 March 1932–July 1949 May 1971	Reopened as underground mine in 1949; closed in May 1971.
Koffiefontein	July 1870	1870	1977	August 1914–January 1916 January 1921–May 1923 June 1932–August 1971 June 1982–March 1987	Resumed as open pit mine in 1971; changed to underground in 1977; closed in June 1982; reopened in March 1987; still active.
De Beers	May 1871	1871	1884	July 1908–June 1963 November 1990	Closed in November 1990
Kimberley	July 1871	1871	1882	July 1914	Closed in July 1914.
Wesselton	September 1890	1893	1909	August 1914–January 1916 March 1921–March 1924 March 1932–January 1939 September 1940–April 1947 January 1953–May 1957	Still active.
Premier	January 1903	1903	1946	August 1914–July 1916 March 1932–1946	Reopened in 1946 to develop an underground mine; full production started in 1949; still active.
Finsch	1958	1966	1990		Changed to an underground mine in September 1990; still active.
Letseng	1957	1977		October 1982	Closed in October 1982.
Orapa	1967	1971			Large active open pit mine.
Letlhakane	1968	1976			Active open pit mine.
Jwaneng	1973	1982			Large active open pit mine.
Venetia	1980	1990			Large active open pit mine.

[a] *Information gathered from* Mineral Industry *(1915–1942),* De Beers Annual Reports, *and the CSO.*

ally from late 1922 through January 1926. World production rose rapidly, to nearly 8 million carats in 1927, but this was mainly due to production from newly discovered alluvial fields at Lichtenburg and beach deposits in Namaqualand, both in South Africa (see Janse, 1995, pp. 239–242), as well as increased production from the Belgian Congo (now Zaire), Angola, and West Africa (i.e., the Gold Coast [now Ghana]). Combined, African alluvial sources represented as much as 60% of world production in 1929. This was the third and most serious challenge so far to the stability of the regulated diamond market.

The Second London Buying Syndicate—the Oppenheimer Syndicate. In the meantime, Anglo American had purchased shares in De Beers, Forminière (Belgian Congo), Diamang (Angola), and CAST (Gold Coast); due to its growing influence

among major diamond producers, it had become the major partner in the Diamond Syndicate. The other key partners were Dunkelsbühler, Barnato Brothers, and JCI (Johannesburg Consolidated Investment Co.). From 1926 to 1930, the reorganized Syndicate was known as the Oppenheimer Syndicate. Ernest Oppenheimer, who had formed both Anglo American and CDM, had become a director of De Beers in December 1925 and its chairman in 1929. To stabilize the market, the Oppenheimer Syndicate renewed all contracts to purchase pipe-mine diamonds from De Beers, beach diamonds from CDM, and alluvial diamonds from Diamang (Angola), Forminière (Belgian Congo [now Zaire]), and CAST (Gold Coast [now Ghana]). In 1929, it held stocks equal to the total production of South Africa for one year. The quota system of 1914, renewed in 1920, stayed in force.

The Period 1931–1939: The Great Depression and the Diamond Corporation. As production from sources outside South Africa increased, De Beers sought greater capital to purchase these diamonds. So Oppenheimer invited the South African diamond producers, who had organized themselves into the Diamond Producers' Association, to join the buying syndicate. After protracted negotiations, the Diamond Corporation was formed in 1930 and new quotas were set: Union of South Africa (State Alluvial Diggings)—10%, CDM—14%, Diamond Corporation (to dispose of existing stock)—15%, Diamond Corporation (to buy outside production)—16%, De Beers—30%, Jagersfontein—6%, Premier—6%, Cape Coast Exploration (the Kleinzee coastal deposits)—2%, and Koffiefontein—1%. The Diamond Corporation also secured long-term contracts (usually five years) to buy the production of the major producing companies, that is, Forminière (Congo), Diamang (Angola), and CAST (Gold Coast and Sierra Leone).

By June 1932, De Beers had completed the purchase of all the outstanding shares of Premier, Jagersfontein, Koffiefontein, and CDM, which made these companies subsidiaries of De Beers and simplified the corporate structure. It also moved its corporate headquarters from London to Kimberley.

The Great Depression of the 1930s increased the difficulties in keeping prices under control. By 1932, De Beers had closed all their operating kimberlite pipe mines (Bultfontein, Dutoitspan, Wesselton, Jagersfontein, Koffiefontein, and the Premier; table 5) and their beach mines in Namaqualand and South West Africa ("De Beers mines close down," 1932). The State Alluvial Diggings (Namaqualand, South Africa) kept producing, but at a reduced rate. All the smaller producers in South Africa also stopped mining operations, although a few still produced diamonds from tailings. In contrast, the Belgian Congo (now Zaire) stepped up production. It became the leading diamond producer by a large margin. Although the three De Beers mines at Kimberley and, on a small scale, the beach mines in Namaqualand and South West Africa (Namibia), were re-opened during the period from late 1935 to early 1939, all of South Africa plus South West Africa accounted for only 10% of the world's diamonds in 1939, compared to 68% for the Belgian Congo (see table 2). The Premier remained closed until 1946.

To deal with the increase in production outside South Africa and South West Africa, the Syndicate was restructured in 1934. Buying was channeled through the Diamond Corporation, and sorting and selling were channeled through the newly formed Diamond Trading Company. The selling agency became known as the Central Selling Organisation (CSO), and the first "sight" was held in 1939.

The Period 1940 to 1990: Post–World War II Challenges and the Emergence of Independent African states. After World War II, several key events further diminished the importance of southern Africa as a diamond producer. They were: (1) the 1940 discovery of a large economic kimberlite pipe in northwestern Tanganyika; (2) the large increase in illegal diamond digging (also called IDD) by local people on concessions held largely by expatriate companies, mainly in West Africa and Central Africa, and illegal diamond buying (also called IDB) by unlicensed buyers from the mid-1950s on; (3) the discovery of many diamondiferous kimberlite pipes in Siberia; and (4) the discovery of a highly diamondiferous lamproite pipe in Australia.

Williamson's Mine at Mwadui. Immediately following World War II, the percentages produced by the various diamond-producing countries changed little. By 1949, however, output at the Williamson mine at Mwadui, in what is now Tanzania, had reached 10% of world production by value (although only 2% by weight). Williamson did not join the Diamond Producers Association, but kept his options open to sell diamonds outside the Diamond Corporation, which he sometimes did.

The Syndicate in 1955, IDB, and IDD. The high incidence of illegal diamond digging and illegal diamond buying since 1955 in Sierra Leone, Guinea, Liberia, Ivory Coast, and Zaire has also caused problems for the Syndicate. Estimates for the annual illicit production of diamonds in each country for the period 1955–1965 are on the order of several million carats. The Diamond Corporation formed subsidiaries in the West African countries and set up local buying offices. In 1955, the quotas were changed as follows: De Beers—25%, Diamond Corporation (which purchased most of the production from countries outside of South Africa)—35%, Premier—4%, Union of South Africa (the Alexander Bay State Diggings)—10%, and CDM—26% (Lenzen, 1970). By 1965, the measures seemed to have had some level of success in stabilizing the diamond market.

The Challenge of Siberia. Diamondiferous kimberlite pipes were discovered from 1954 onward in Siberia in the USSR territory of Yakutia (now the Republic of Sakha within the Russian Federation). The Siberian discoveries shattered the myth that large economic kimberlite pipes were restricted to the African continent. A good, early account in English of the Siberian diamond fields is given by Davidson (1957, 1960).

The first pipe, named Mir (Peace), came into production in 1957. Subsequently, Russia's contribution to world production rose from an insignificant amount (derived from placer deposits in the Ural Mountains) at the time of the Mir pipe's discovery, to 18% in 1969 and 27% in 1979. During this same period, the mainly eluvial, colluvial, and alluvial production from the Belgian Congo (now Zaire) and C.A.R. declined because of the civil wars that ensued after Zaire became an independent state in 1960—from 56% in 1959 and 35% in 1969, to 23% in 1979 (table 2). Consequently, the proportion of pipe-mine production rose. This is particularly evident in the share represented by southern Africa, that is, South Africa and Botswana combined, which is primarily from pipes (but in South Africa also includes some alluvials): It rose from 11% in 1959 and 20% in 1969, to 32% in 1979 (table 2). This was due largely to the output from the new pipe mines that came on stream in the 1960s (i.e., Finsch in South Africa) and the 1970s (i.e., Orapa and Letlhakane in Botswana).

Diamonds Found in Lamproite in Australia. The most remarkable event in diamond exploration in this century was the discovery of a hitherto unknown type of diamond host rock—olivine lamproite—that was found to contain very high grades of diamond in the Argyle pipe in northwestern Australia. Discovered in late 1979, the pipe came into full production in 1986, when it captured up to 35% of the world's diamond production by weight, although it was only 7% by value, similar to that in 1994 (table 3). The production from Argyle, combined with that from the Siberian pipes, severely reduced Africa's significance. Argyle's production also shifted all other percentages, with the result that in 1994 (the most recent year for which figures are now available) pipe-mine production stood at 80%, while alluvial production was 18% and beach, tidal zone, plus off-shore production was 2% (table 2).

DIAMOND PRODUCTION TODAY

Current Production. Botswana and South Africa produce the largest amount of diamonds by value on the African continent—23% and 20% of world production, respectively, in 1994 (table 3). For Zaire, this figure is 9%, for Namibia it is 6%; and for Angola it is 4%. The percentages for production by weight are significantly different: Zaire, 17%; Botswana, 14%; South Africa, 10%; Angola, 1%; and Namibia 1%. A comparison of these two sets of figures shows the great significance of the value of the Botswana plus South Africa production (pipe and alluvial), the very high value of the Namibia (beach and submarine deposits) and Angola (alluvial) diamonds, and the low value of the Zaire (Mbuji-Mayi eluvial and colluvial) deposits. Area, grade, value per carat, volume, and other data for selected pipes are summarized in table 4.

South Africa. *Pipe and Fissure Mines.* Three of the original five kimberlite pipe mines around Kimberley (Bultfontein, Dutoitspan, and Wesselton) are still active (table 5). However, the importance of the Kimberley mines is diminishing as underground development goes deeper, into narrower areas of the pipes where the reserves are correspondingly smaller. Thus, mining costs will eventually overtake revenue and the mines will have to close, possibly as early as the next decade if current (quota-dependent) production levels—between 500,000 and 600,000 carats per year for all three mines—are maintained. Depths in 1993 were 845 m (2,772 feet) below the surface at Bultfontein, 870 m at Dutoitspan, and 995 m at Wesselton.

About 400 m below the surface, the Premier kimberlite pipe is cut by a sill (a horizontal intrusion of igneous rock) of gabbro (an igneous rock consisting of plagioclase and pyroxene, not containing diamonds) that is about 75 to 80 m thick (McMurray, 1979). The ore reserves above the sill are virtually mined out, and a new mine had to be created to exploit the ore below the sill, from which nearly all current production is derived. The below-sill ore reserves are very large, which assures a long life for the Premier mine. Because of quota allotments, production at the Premier went from 2.5 million carats in 1988 to 1.6 million carats in 1994 (*De Beers Annual Reports* for 1988 and 1994).

The Koffiefontein mine has reached a depth of 370 m (1,213 feet) in underground workings, and produces between 125,000 and 135,000 carats per year. The future of this mine depends on whether or not the grade decreases.

The Finsch mine (figure 12) went underground in September 1990, when the open pit reached a depth of 430 m (1,410 feet); in 1994, all ore was drawn from underground workings. Production levels are between 2.5 and 3 million carats annually. The open-pit Venetia mine produces 5 million carats per year (again, see figure 11). Reserves at the Finsch and, especially, the new Venetia mine are sufficient to maintain South African production at the present level for the next two to three decades. Several small companies are actively mining diamond-bearing fissures, such as the Star mine (in Orange Free State). Such fissures may account for up to 1% of pipe-mine production.

Alluvials. De Beers, Transhex, and Alexcor are still actively mining the alluvial deposits in Namaqualand, such as the Buffels River complex and the beach deposits along the coast.

Off-Shore Deposits in Namaqualand (South Africa) and Namibia. The world's largest diamond reserves may lie on the continental shelf off the coasts of Namibia and Namaqualand. Great efforts are being made to improve the technology needed to evaluate and mine these ocean deposits, and their production is likely to overtake that of all other sources in southern Africa, except perhaps the largest pipe mines such as Jwaneng and Orapa in Botswana. De Beers is at the forefront of research on undersea exploration; after years of exploration activities, they officially started mining operations off the coast of Namibia in 1991 to replace their dwindling reserves of on-shore beach deposits. De Beers is actively prospecting off the coast of Namaqualand, and several small companies are actually mining diamonds near-shore and in the tidal zone.

Figure 12. A large production rig is used to mine underground at South Africa's Finsch mine, which currently produces between 2.5 and 3 million carats a year. Photo courtesy of De Beers South Africa.

Recently, (Australia-based) BHP has shown interest in the Namibian and Namaqualand undersea deposits. BHP is also likely to invest much in improving the necessary technology.

Namibia. The on-shore beach deposits in Namibia are now mined by newly formed Namdeb. Although most Namibian diamonds still come from these on-shore deposits, an increasing proportion is being derived from off-shore activities. In 1994, the latter represented 31% of total Namibian production (*De Beers Annual Report*, 1995).

Namdeb is actively mining an alluvial terrace deposit at Auchas, on the northern (Namibian) bank of the Orange River (figure 13). It has been projected that the mine will produce 45,000 carats of relatively large, good-quality diamonds each year for the next decade

Botswana. In 1994, Botswana was the highest-*value* diamond producer in Africa (and the world, accounting for 23% of world production by value), and second largest in Africa by weight (14% of world production). In Africa, only Zaire produced

Figure 13. At the alllu-vial terrace deposit known as Auchas, on the Namibian bank of the lower Orange River, this prospecting trench has been cut through the deep overburden to reach the diamond-bear-ing gravels. Photo by Manfred Marx.

more stones (17% of world total), but these repre-sented only 9% by value. All Botswana diamonds are derived from three open-pit kimberlite pipe mines: Orapa, Letlhakane, and Jwaneng. Jwaneng is the world's largest and richest kimberlite-pipe mine—54 ha (133 acres) with a grade of 1.37 ct/t in 1994 and a value per carat of $110 (table 4), for a value per tonne of ore of $150. Jwaneng (figure 14) produced 9 million carats in 1994. The figures for Orapa and Letlhakane 1 are, respectively: grade, 0.68 and 0.38 ct/t; value per carat, $50 and $120; and value per tonne of ore, $34 and $46 (table 4). These three mines have very large ore reserves, sufficient to maintain Botswana diamond production at the present level (15 to 16 million carats annually) for several decades.

Angola. The potential reserves of kimberlite pipes and alluvial deposits in Angola are large. Since 1975, however, civil war and social unrest have prevented systematic exploration for new pipes and detailed evaluation of known pipes. As political and social conditions gradually stabilize, many companies will start prospecting and will seek to secure evaluation and mining rights over several known pipes. Pipes will have priority over alluvial deposits, because the fact that their ore reserves are stacked vertically, with a minimum surface area, makes them easier to manage and secure than allu-vial deposits. Production from Angola is likely to increase greatly; in the next decade, it may over-take South Africa (10 million carats annually at present), but it probably will not surpass Botswana (16 million carats at present).

Zaire. International companies are currently involved in very little prospecting because of the generally chaotic and unsafe conditions in this country. Official diamond production has declined greatly, from 24 million carats in 1990 to 17 mil-lion carats in 1994 (table 3).

West Africa. It is likely that the diamond potential of the central part of the West African craton, buried under Tertiary and Recent sediments in the western part of the Sahara (Mauritania, Mali, southern Morocco, and southwestern Algeria) will be investigated in the first decade of the next cen-tury or perhaps even in this decade. Given the lim-ited information presently available, no prediction as to the scope and success ratio of these investiga-tions can be ventured. My personal feeling is that the success ratio will be high.

West Africa currently supplies 1.4% by weight and 4.5% by value of world production (table 3).

FUTURE TRENDS

I believe that Africa will continue to be a major—if not again become *the* major—diamond producer for a number of reasons. First, it is projected that the proven ore deposits of the open pit at Argyle will be depleted before 2005, and the economics of under-

ground mining are still in doubt. Second, in eastern Russia (Yakutia), all but one (Udachnaya) of the current Siberian pipes are almost mined out, and complete financing has not yet been obtained for the development of the Jubilee and Botubiya pipes. Consequently, production is not likely to increase significantly in the near future. Third, in northern Russia, the Archangel prospects are still in the early stages of development, and little international funding has been obtained to date. It is unlikely, therefore, that a significant mine will be in operation before 2005. Fourth, the projected diamond mine in the Northwest Territories of Canada, to be managed by BHP, is not likely to be fully operational before 1998; even so, it has an estimated production of only 2–3 million carats a year. Thus, it is unlikely to have any significant impact on the world diamond market.

In Africa, the dwindling reserves of the Kimberley mines, the on-shore beach deposits in Namaqualand and Namibia, and the eluvial and alluvial deposits at Mbuji-Mayi in Zaire will be more than offset by production from the off-shore submarine deposits, which are an enormous resource. It would also be possible to increase production at the large pipe mines at Finsch, Orapa, Jwaneng, and Venetia, which are currently underproducing. There is the possibility, too, of major new deposits in Angola. Consequently, I believe that the proportion of world production represented by Africa will not decline further and might even increase.

CONCLUSION

Africa has a 130-year history of diamond production that in general has been high in both quantity and quality. Discovery of the primary diamond host rock—kimberlite—stimulated the development of theories about the origin of diamonds and generated a wide range of scientific research on mineral inclusions in diamonds, on deep-seated xenoliths (such as eclogites and garnet peridotites), and, in general, on the composition of the Earth's crust and mantle. Despite the opening of several large diamond mines in Siberia and Australia since the 1960s, Africa is still the most important producer of diamonds, with 46% of world production by weight and 69% by value in 1994. Two of the world's most important diamond sources—Zaire by weight and Botswana by value—lie on the African continent. Because of the increase in production from kimberlite pipes in South Africa and Botswana, from enormous resources in submarine deposits off-shore from Namibia and South Africa, and possible increased future production from Angola, Africa will maintain its prominent position in world diamond production.

Figure 14. Botswana's Jwaneng mine, opened in 1982, produced 9 million carats of diamonds in 1994. It is the largest and richest kimberlite mine in the world. Photo courtesy of the Central Selling Organisation.

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Errata to Part I (Janse, 1995): *In the caption to figure 14 (p. 242), the date the Premier mine closed should be 1932. Figure 25 (p. 252) features a 128 ct fancy yellow diamond owned by Tiffany; it is not the original Tiffany diamond, which is a 128.51 ct square antique modified billiant cut. The Boocock (1960) Reference should be p. 4, not Vol. 4.*

REFERENCES

Bardet M.G. (1950) Note sur des nouveaux gisements diamantifères dans le birrimien inférieur de Côte d'Ivoire suivie de remarques sur la géologie du diamant dans l'ouest africain [A note on the new diamondiferous deposits of Lower Birrimean age in Ivory Coast followed by some remarks on the geology of the diamond in West Africa]. *Chronique des Mines Coloniales*, Vol. 19, No. 178, pp. 90–98.

Bardet M.G. (1973) *Géologie du Diamant, Vol. 1, Généralités.* Bureau de Recherches Géologiques et Minières (BRGM) Memoire 83, Paris, France, 232 pp.

Bardet M.G. (1974) *Géologie du Diamant, Vol. 2, Gisements de diamant d'Afrique.* Bureau de Recherches Géologiques et Minières (BRGM) Memoire 83, Paris, France, 229 pp.

Bardet M.G. (1977) *Géologie du Diamant, Vol. 3, Gisements de diamant d'Amérique, d'Europe, d'Asie, et d'Australasie.* Bureau de Recherches Géologiques et Minières (BRGM) Memoire 83, Paris, France, 169 pp.

Barnes J.W. (1961) *The Mineral Resources of Uganda.* Geological Survey of Uganda, Kampala, Bulletin No. 4, 89 pp.

Beck R. (1898) Die Diamantenlagerstätte von Newland in Griqua Land West [The diamond deposits at Newland in Griqualand West]. *Zeitschrift für praktische Geologie*, Vol. 1898, pp. 163-164.

Boberg W. (1992) Diamond and gold exploration in Liberia, West Africa. Abstract of talk given in September at the Colorado School of Mines, Boulder.

Bonney T.G. (1899) The parent-rock of the diamond in South Africa. *Geological Magazine*, Decade 4, No. 6, pp. 309–321.

Boocock C. (1960) Three small diamonds found in Bamangwato Tribal Territory. In the *Annual Report of the Bechuanaland Geological Survey Department for the Year 1960.*

Boocock C. (1965) Mineral resources of the Bechuanaland Protectorate. *Overseas Geology and Mineral Resources*, Vol. 9, No. 4, pp. 369–417.

Bridge Oil withdraws from Aredor (1994) *Diamond International*, No. 29, May/June, p. 24.

Bruton E. (1978) *Diamonds*, 2nd ed. Chilton Book Co., Radnor, PA.

Buttgenbach H. (1909) Sur une roche diamantifère trouvée au Congo Belge. *Annales de la Société Géologique de Belgique*, Vol. 36, pp. 77–79.

Buttgenbach H. (1925) Minéralogie du Congo Belge. *Mémoires de la Société Royale des Sciences de Liege*, Série 3, Vol. 13, pp. 108–117.

Choubert B. (1946) Sur la présence de diamant au Gabon (A.E.F.) en relation avec des kimberlites et des roches carbonatées métamorphiques [On the occurrence of diamond in Gabon in relation to kimberlites and metamorphic carbonate-rich rocks]. *Comptes Rendus des Séances de l'Académie des Sciences*, Paris, Vol. 223, pp. 638–640.

Clement C.R. (1982) *A Comparative Geological Study of Some Major Pipes in the Northern Cape and Orange Free State.* Unpublished Ph.D. Thesis, University of Cape Town, 432 pp.

Clifford T.N. (1966) Tectono-metallogenic units and metallogenic provinces of Africa. *Earth and Planetary Science Letters*, Vol. 1, pp. 421–434.

Cohen E. (1872) Geologische Mittheilungen über das Vorkommen der Diamanten im Süd Afrika [Geological notes on the occurrence of diamonds in South Africa]. *Neues Jahrbuch für Mineralogie, Geologie und Palaeontologie*, Vol. 1872, pp. 857–861.

Cohen E. (1874) Erklärung gegen Dunn, dessen Bemerkungen, das Vorkommen der Diamanten in Afrika, betreffend [Statement against Dunn regarding his remarks on the occurrence of diamonds in Africa]. *Neues Jahrbuch für Mineralogie, Geologie und Palaeontologie*, Vol. 1874, pp. 514–515.

Cohen E. (1877) Titaneisen von den Diamantfeldern in Süd-Afrika [Ilmenite from the diamond fields in South Africa]. *Neues Jahrbuch für Mineralogie, Geologie und Palaeontologie*, Vol. 1877, pp. 695–697.

Cohen E. (1879) Über einen Eklogit, welcher als Einschluss in den Diamant gruben von Jagersfontein, Orange Freistaat, Süd-Afrika vorkommt [About an eclogite that occurs as an inclusion in the diamond digging at Jagersfontein, Orange Free State, South Africa]. *Neues Jahrbuch für Mineralogie, Geologie und Palaeontologie*, Vol. 1879, pp. 864–869.

Cohen E. (1889) Ueber den Granat der südafrikanischen Diamantfelder und über Chromgehalt der Pyrope [Note on the garnet of the South Africa diamond fields and the chrome content of pyropes]. *Mittheilungen aus dem naturwissenschaftlichen Verein für Neu-Vorpommern und Rügen in Greifswald*, Vol. 20, pp. 149–152.

Colonel Jack Scott finds first diamonds in Maluti Mountains, 1954 (1978) *Indiaqua*, No. 18, pp. 19–20.

Cooper G.C. (1874) On the origin and present position of the diamonds of South Africa. *Proceedings of the Geologists' Association*, Vol. 3, pp. 336–343.

Danielson V., Christie B. (1993) Casierra diamond syndicate . . . In: Vancouver junior buying into South African diamond mines. *Northern Miner*, Vol. 79, No. 39, November 29, p. 6.

Danielson V., Christie B. (1994) The Sierra Leone government has granted . . . . In: Investors await drill results from Saskatchewan diamond play. *Northern Miner*, Vol. 79, No. 51, February 21, p. 6.

Davidson C.F. (1957) The diamond fields of Yakutia. *Mining Magazine*, Vol. 92, No. 6, pp. 329–338.

Davidson C.F. (1960) The diamond fields of Yakutia. *Mining Magazine*, Vol. 103, No. 4, pp. 205–213.

De Beers mines close down (1932) *Mining Magazine*, March, p. 135.

De Beers returns to Sierra Leone (1994) *Diamond International*, No. 31, September/October, p. 31

The diamond conference (1914) *South African Mining and Engineering Journal*, Vol. 23, Part 2, August 8, p. 629.

Diamond sales under investigation (1992) *Diamond International*, July-August, pp. 25–26.

The diamond situation (1930) *Mining Magazine*, Vol. 43, No. 4, October, pp. 196–197.

Dirlam D.M., Misiorowski E.B., Tozer R., Stark K.B., Bassett A.M. (1992) Gem wealth of Tanzania. *Gems & Gemology*, Vol. 28, No. 2, pp. 80–102.

Dunn E.J. (1874) On the mode of occurrence of diamonds in South Africa. *Quarterly Journal of the Geological Society of London*, Vol. 30, pp. 54–60.

Dunn E.J. (1881) Notes on the diamond-fields, South Africa, 1880. *Quarterly Journal of the Geological Society of London*, Vol. 37, pp. 609–612.

Edwards C.B., Howkins J.B. (1966) Kimberlites in Tanganyika with special reference to the Mwadui occurrence. *Economic Geology*, Vol. 61, No. 3, pp. 537-554.

Even-Zohar C. (1993) The state of the diamond industry: Optimism returns. *Mazal U'Bracha*, Vol. 55, December, p. 75 et passim.

Fleming I. (1957) *The Diamond Smugglers.* Jonathan Cape, London, 160 pp.

Gawaine J. (1976) *The Diamond Seeker: The Story of John Williamson.* MacMillan, Johannesburg, 184 pp.

Gerryts E. (1988) Memories of Mwadui in the 1950s. *Indiaqua*, No. 49, pp. 21–31.

Gobba J.M. (1989) Kimberlite exploration in Tanzania. *Journal of African Earth Sciences*, Vol. 9, No. 3/4, pp. 565–578.

Grantham D.R., Allen J.B. (1960) Kimberlite in Sierra Leone. *Overseas Geology and Mineral Resources*, Vol. 8, No. 1, pp. 5–25.

Griffin W.L., Cousens D.R., Ryan C.G., Sie S. H., Sutter G.F. (1989) Ni in chrome pyrope garnets: A new geothermometer. *Contributions to Mineralogy and Petrology*, Vol. 103, No. 2,

pp. 199–202.
Gurney J.J. (1985) A correlation between garnets and diamonds in kimberlites. In J. E. Glover and P. G. Harris, Eds., *Kimberlite Occurrence and Origin: A Basis for Conceptual Models in Exploration*. Geology Department and University Extension, University of Western Australia, Publication No. 8, pp. 143–166.
Gurney J.J. (1989) Diamonds. In J. Ross, Ed., *Kimberlites and Related Rocks, Vol. 2, Proceedings of the Fourth International Kimberlite Conference, Perth, 1986*, Geological Society of Australia Special Publication No. 14, Blackwell Scientific Publications, Oxford, pp. 935–965.
Gurney J.J., Switzer G.S. (1973) The discovery of garnets closely related to diamonds in the Finsch Pipe, South Africa. *Contributions to Mineralogy and Petrology*, Vol. 39, pp. 103–116.
Haggerty S.E. (1994) Superkimberlites: A geodynamic diamond window to the Earth's core. *Earth and Planetary Science Letters*, Vol. 122, No. 1-2, pp. 57–69.
Hall P.K. (1970) *The Diamond Fields of Sierra Leone*. Geological Survey of Sierra Leone Bulletin 5, 133 pp.
Harbottle M. (1976) *The Knaves of Diamonds*. Seeley Service & Co., London.
Hartwell J.W., Brett B.A. (1962) Gem stones. *Minerals Yearbook 1961, Vol. 1, Metals and Minerals*, U.S. Department of Interior, Washington, D.C., pp. 583–596.
Hatch F.H. (1912) Description of a diamondiferous gem gravel from the west coast of Africa. *Geological Magazine*, Decade 5, Vol. 9 No. 3, pp. 106–110.
Haut F.R., Levin P., Eisenburger D. (1984) Diamantführende Ultrabasite in Obervolta [Diamondiferous ultrabasics in Upper Volta]. *Geologisches Jahrbuch*, Series A, Vol. 75, pp. 361–378.
Hawthorne J.B., Carrington A.J., Clement C.R., Skinner E.M.W. (1979) Geology of the Dokolwayo kimberlite and associated palaeo-alluvial deposits. In F.R. Boyd and H.O.A. Meyer, Eds., *Kimberlites, Diatremes, and Diamonds: Their Geology, Petrology, and Geochemistry*, Vol. 1, Proceedings of the Second International Kimberlite Conference, American Geophysical Union, Washington, DC, pp. 59–70.
Holmes A., Paneth F.A. (1936) Helium-ratios of rocks and minerals from the diamond pipes of South Africa. *Proceedings of the Royal Society* (London), Series A, Vol. 154, No. A 882, pp. 385–413.
How Dr. Williamson nearly missed finding the Mwadui Diamond Pipe (1974) *Indiaqua*, No. 9, pp. 19–21.
Janse A.J.A. (1993) The aims and economic parameters of diamond exploration. In P. Sheahan and A. Chater, Eds., *Diamonds: Exploration, Sampling and Evaluation, Proceedings of a Short Course on Diamond Exploration, Toronto, 1993*. Prospectors and Developers Association of Canada, Toronto, pp. 173–184.
Janse A.J.A. (1994) Is Clifford's Rule still valid? Affirmative examples from around the world. In H.O.A. Meyer and O. Leonardos, Eds., *Proceedings of the Fifth International Kimberlite Conference, Vol. 2, Diamonds: Characterization, Genesis and Exploration*, Companhia de Pesquisa de Recursos Minerais (CPRM), Rio de Janeiro, Brazil, pp. 215–235.
Janse A.J.A. (1995) A history of diamond sources in Africa: Part 1. *Gems & Gemology*, Vol. 31, No. 4, pp. 228–255.
Janse A.J.A., Sheahan P.A. (1995) Catalogue of world wide diamond and kimberite occurrences: A selective and annotative approach. In W.L. Griffin, Ed., Diamond exploration into the 21st century, *Journal of Geochemical Exploration*, Vol. 53, Nos. 1-3, pp. 73–111.
Jennings C.M.H. (1995) The exploration context for diamonds. In W.L. Griffin, Ed., Diamond exploration into the 21st century, *Journal of Geochemical Exploration*, Vol. 53, Nos. 1-3, pp. 113–124.
Junner N.R. (1943) The Diamond Deposits of the Gold Coast, with Notes on Other Diamond Deposits in West Africa. Gold Coast Geological Survey, Bulletin No. 12, Accra, Ghana, 52 pp.
Kamil F. (1979) *The Diamond Underworld*. Allen Lane, London, 244 pp.
Kaminskiy F.V., Verzhak V.V., Dauev Yu.M., Buima T., Boukhalfa L., Kaui M., Salhi A., Slugi M. (1992) The North-African diamondiferous province. *Russian Geology and Geophysics*, Vol. 33, No. 7, pp. 91–95.
Kinny P. D., Meyer H.O.A. (1994) Zircon from the mantle: A new way to date old diamonds. *Journal of Geology*, Vol. 102, No. 4, pp. 475–481.
Kirkley M.B., Gurney J.J., Levinson A.A. (1991) Age, origin and emplacement of diamonds: Scientific advances in the last decade. *Gems & Gemology*, Vol. 27, No. 1, pp. 2–25.
Kitson A. (1919) The discovery of diamonds at Abomoso, Eastern Province. Gold Coast Sessional Paper No. 9 of 1918/1919.
Knopf D. (1970) *Les kimberlites et les roches apparentés de Côte d'Ivoire* [Kimberlite and related rocks of Ivory Coast]. Sodemi, Abidjan, 202 pp.
Kramers J.D. (1979) Lead, uranium, strontium, potassium and rubidium in inclusion-bearing diamonds and mantle-derived xenoliths from southern Africa. *Earth and Planetary Science Letters*, Vol. 42, No. 1, pp. 58–70.
Kunz G.F. (1911) Precious stones. In A.H. Faye, Ed., *The Mineral Industry: Its Statistics, Technology and Trade during 1910*, Vol. 19. McGraw-Hill, New York, pp. 563–581
Kunz G.F. (1920) Precious stones. In G.A. Rousch, Ed., *The Mineral Industry: Its Statistics, Technology and Trade during 1919*, Vol. 28. McGraw Hill, New York, pp. 584–608.
Laan H.L. van der (1965) *The Sierra Leone Diamonds*. Oxford University Press, Oxford, 228 pp.
Lacroix A. (1897) *Minéralogie de la France et de ses Colonies*. Vol. 2. Librairie Polytechnique, Baudry et Cie., Paris, France.
Lebedeff V., Choubert B. (1934) Les terraces du moyen Congo: Composition minéralogique du gravier [The terraces of the middle stretch of the Congo: Mineralogical composition of the gravels]. *Chronique des Mines*, No. 28, pp. 218–222.
Legrand J., Ed. (1984) *Diamonds, Myth, Magic and Reality*, rev. ed. Bonanza Books, New York, 287 pp.
Lenzen G. (1970) *The History of Diamond Production and the Diamond Trade*. Barrie and Jenkins, London, 230 pp.
Levinson A.A., Gurney J.J., Kirkley M.B. (1992) Diamond sources and production: Past, present, and future. *Gems & Gemology*, Vol. 28, No. 4, pp. 234–254.
Lewis C. (1888) The matrix of the diamond. *Geological Magazine*, Decade 3, Vol. 5, pp. 129–131.
Lewis H.C. (1897) *Papers and Notes on the Genesis and Matrix of the Diamond*. T. G. Bonney, Ed., Longmans, Green and Co., London, 72 pp.
Linari-Linholm A.A. (1969) Diamond recovery is big business. *Engineering and Mining Journal*, Vol. 170, No. 11, pp. 67–80.
MacNevin A.A. (1977) *Diamonds in New South Wales*. Geological Survey of New South Wales, Mineral Resources No. 42, Sydney, Australia.
McCurry P. (1973) Geology of degree sheet 21, Zaria, Nigeria. *Overseas Geology and Mineral Resources, No. 45*, Institute of Geological Sciences, London.
McMurray S. (1979) Doing the impossible at Premier: Defeat of the gabbro sill opens vast new diamond reserves. *Coal, Gold + Base Minerals of Southern Africa*, October, pp. 51–52 et passim.
Mennell F.P. (1906) Somabula diamond field of Rhodesia. *Geological Magazine*, Decade 5, Vol. 3, No. 508, pp. 459–462.
Mennell F.P. (1908) Note on the Rhodesian diamond fields. *Transactions of the Geological Society of South Africa*, Vol. 11, pp. 43–44.
Merensky H. (1909) The diamond deposits of Lüderitzland, German South-West Africa. *Transactions of the Geological*

Society of South Africa, Vol. 12, pp. 13–23.
Metals & Minerals Annual Review (1995) Mining Journal, London, pp. 26-27, 30–31.
Meunier E.S. (1877) Composition et origine du sable diamantifére de Du Toit's Pan (Afrique australe) [Composition and origin of the diamondiferous sand-sized fraction at Dutoitspan, South Africa]. *Comptes Rendus hebdomadaires des Séances de l'Académie des Sciences*, Vol. 84, pp. 250–252.
Meunier E.S. (1882) Examen minéralogique des roches qui accompagnent le diamant dans les mines du Cap de Bonne-Espérance [Mineralogical examination of the rocks that accompany diamond in the mines of the Cape of Good Hope]. *Bulletins de l'Académie Royale des Sciences, des Lettres et des Beaux-Arts de Belgique*, Third Series, Vol. 3, pp. 374–404.
Middleton J.L. (1932) Diamonds in Equatorial Africa. *Engineering and Mining Journal*, Vol. 133, No. 5, p. 285.
The Mineral Industry: Its Statistics, Technology and Trade (1915–1942) McGraw Hill, New York.
Minerals Yearbook (1943–1966) U.S. Bureau of Mines, U.S. Department of Interior, Washington, D.C.
Mining Annual Review (1967–1990) The Mining Journal, London.
Mink Mineral Resources Inc., diamonds and gold in Mali. (1993) *Northern Miner*, Vol. 79, No. 29, September 20, p. 23.
Mitchell R.H. (1986) *Kimberlites: Mineralogy, Geochemistry, and Petrology*. Plenum Press, New York, 442 pp.
Mitchell R.H., Bergman S.C. (1991) *Petrology of Lamproites*. Plenum Press, New York, 447 pp.
Molengraaff G.A.F. (1897) Diamond at Rietfontein. *Transactions of the Geological Society of South Africa*, Vol. 3, pp. 122–123.
Morton W.J. (1877) South African diamond fields and the journey to the mines. *Bulletin of the American Geographical Society*, Vol. 4 (Session for 1876–77), pp. 3–30.
Newbury C. (1989) *The Diamond Ring: Business, Politics, and Precious Stones in South Africa, 1867–1947*. Clarendon Press, Oxford, 431 pp.
Norman D.I., Ward J., McKittrick S. (1996) Hosts and sources of Ghana diamonds. Paper given at the SME/AIME annual meeting, Phoenix, AZ, March 11.
Partridge F.C. (1935) The identification of kimberlite and kimberlite minerals by spectroscopic and other methods. *Transactions of the Geological Society of South Africa*, Vol. 37, pp. 205–211.
Pollett J.D. (1937) The diamond deposits of Sierra Leone. *Bulletin of the Imperial Institute* (London), Vol. 35, No. 3, pp. 333–348.
Raoult J.F., Velde D. (1971) Découverte de trachytes potassiques à olivine et d'andésites en coulées dans le Miocène continental au Sud du Kef Hahouner (Nord du Constantinois, Algérie) [Discovery of olivine-bearing potassic trachites and andesite lava flows in the Miocene continental south of Kef Hahouner (north of Constantinois, Algeria)]. *Comptes Rendus de l'Académie des Sciences*, Paris, Série D, Vol. 272, pp. 1051–1054.
Real F. (1958) Sur les roches kimberlitiques de la Lunda (Angola). *Boletim de Museu e Laboratoria Minerais e Geologico. Faculdad Ciencias, Universidad de Lisboa*, Series 7, No. 26, pp. 220–253.
Reunert T. (1893) *Diamonds and Gold in South Africa*. J.C. Juta & Co., Cape Town, South Africa, 242 pp.
Richardson S.H., Gurney J.J., Erlank A.J., Harris J.W. (1984) Origin of diamonds in old enriched mantle. *Nature*, Vol. 310, No. 5974, pp. 198–202.
Rickwood P.C. (1969) The nature and occurrences of non-eclogitic ultramafic xenoliths in the kimberlites of Southern Africa. *Upper Mantle Project*, Special Publication No. 2, Geological Society of South Africa, pp. 395–416.
Rickwood P.C., Gurney J.J., White-Cooper D.R. (1969) The nature and occurrences of eclogite xenoliths in the kimberlites of southern Africa. *Upper Mantle Project*, Special Publication No. 2, Geological Society of South Africa, pp. 371–393.
Robertson M. (1974) *Diamond Fever, South African History 1866–9, from Primary Sources*. Oxford University Press, Cape Town, South Africa, 250 pp.
Rombouts L. (1985) Kimberlites in western Kenya. *Annales de la Société Géologique de Belgique*, Vol. 108, pp. 369–375.
Rombouts L. (1994) Diamond mining still profitable. *Diamond International Business Review*, January-February, pp. 15–26.
Rombouts L. (1995) World diamond mining. *World Diamond Industry Directory and Yearbook, 1995*, special issue of *Diamond International*, pp. 17–21.
Sampling diamond mines (1956) *Mining Magazine*, Vol. 94, No. 5, May, pp. 272–274.
Scheibe R. (1906) Der Blue Ground des Deutsch Südwest Afrika im Vergleich mit dem des englischen Süd Afrikas (The blue ground of German South West Africa compared to that of English South Africa). Programm der königlichen Bergakademie zu Berlin, Feister'schen Buchdruckerei, Berlin, 18 pp.
Scott Smith B.H., Skinner E.M. W., Loney P.E. (1989) The Kapamba lamproites of the Luangwa Valley, eastern Zambia. In J. Ross, Ed., *Kimberlites and Related Rocks. Vol. 1, Proceedings of the Fourth International Kimberlite Conference, Perth, 1986*. Geological Society of Australia Special Publication No. 14, Blackwell Scientific Publications, Oxford, pp. 189–205.
Sheahan P.A. Janse A.J.A. (1994) Diamond details. *Canadian Mining Journal*, Vol. 115, No. 1, pp. 19–23.
Sobolev N.V., Lavrent'ev Yu.G., Pokhilenko N.P., Usova L.V. (1973) Chrome-rich garnets from the kimberlites of Yakutia and their paragenesis. *Contributions to Mineralogy and Petrology*, Vol. 40, pp. 39–52.
Stephenson S. (1994) New start for Ghana diamonds. *Diamond International*, No. 28, March/April, pp. 83–84, 86.
Stockley G.M. (1947) *Report on the Geology of Basutoland*. Government Printer, Maseru, Lesotho, 114 pp.
Sutton J.R. (1918) Kimberley diamonds, especially cleavage diamonds. *Transactions of the Royal Society of South Africa*, Vol. 7, pp. 65–96.
Tanzania: De Beers group is to spend $8m upgrading Williamson Diamonds' Mwadui mine (1995) *Engineering and Mining Journal*, Vol. 196, No. 5, p. 16.
Thebault J.Y. (1959) Problème de le récherche du diamant en pays saharien et plus précisément au Hoggar [Problems in prospecting for diamonds in the Sahara and especially in the Hoggar area]. *Bureau de Recherche Minière d'Algérie, Bulletin de Science et Economique*, No. 6, pp. 65–81.
Wagner P.A. (1914) *The Diamond Fields of Southern Africa*. The Transvaal Leader, Johannesburg, South Africa (reprinted in 1971 by C. Struik, Cape Town, South Africa, 355 pp.).
Wagner P.A. (1926) Note on kimberlite from Tanganyika Territory. *South African Journal of Science*, Vol. 23, pp. 204–205.
Wagner P.A. (1928) The evidence of the kimberlite pipes on the constitution of the outer part of the earth. *South African Journal of Science*, Vol. 25, pp. 127–147.
Walferdin H. (1834) Séance du 20 janvier 1834. *Bulletin de la Société Géologique de France*, Vol. 4, pp. 152–174.
Williams A.F. (1911) The Kimberley system of handling large quantities of ground in the minimum of time, with notes regarding the life of wire ropes. *South African Mining Journal*, Vol. 9, No. 1, pp. 1–18.
Williams A.F. (1932) *The Genesis of the Diamond*, Vols. 1–2. Ernest Benn, London, 636 pp.
Williams G.F. (1905) *The Diamond Mines of South Africa*, Vols. 1–2. B.F. Buck & Co., New York.
Wilson A.N. (1982) *Diamonds: From Birth to Eternity*. Gemological Institute of America, Santa Monica, CA, 450 pp.

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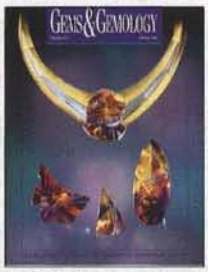
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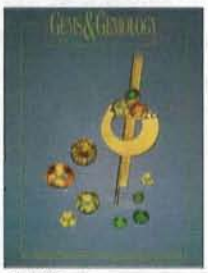
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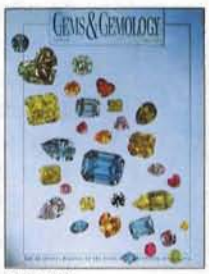
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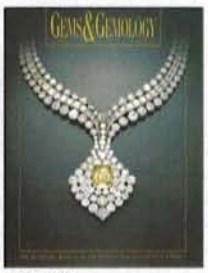
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GEMOLOGICAL INVESTIGATION OF A NEW TYPE OF RUSSIAN HYDROTHERMAL SYNTHETIC EMERALD

By John I. Koivula, Robert C. Kammerling, Dino DeGhionno, Ilene Reinitz, Emmanuel Fritsch, and Mary L. Johnson

Tairus, in Novosibirsk, has produced yet another new type of Russian hydrothermal synthetic emerald, now being marketed in Bangkok. Examination of eight faceted samples revealed that, with the exception of certain characteristic inclusions, the basic gemological properties shown by this new synthetic are essentially the same as those encountered in other hydrothermally grown synthetic emeralds and some natural emeralds. If the characteristic inclusions are not present, distinctive spectral characteristics in both the mid- and near-infrared regions of the spectrum will serve to separate these synthetic emeralds from their natural counterparts.

The first commercially successful hydrothermal synthesis of beryl is generally attributed to Johann Lechleitner who, in 1960, produced hydrothermal synthetic emerald overgrowth on pre-faceted natural beryl (Nassau, 1980). Today, gem-quality hydrothermal synthetic emeralds are available from Innsbruck, Austria (Lechleitner), from the United States (Regency, formerly Linde), from China, from Japan (formerly Biron, which originated in Australia), and from Russia. The focus of this article is a new product from Russia, specifically from the joint-venture company Tairus.

The gemological literature contains useful information on previous examinations of hydrothermal synthetic emeralds from the former Soviet Union (Takubo, 1979; Koivula, 1985; Schmetzer, 1988; Henn et al., 1988; "What to look for . . . ," 1989). Since late 1993, Pinky Trading Co. of Bangkok, Thailand, has been marketing a hydrothermally grown synthetic emerald with internal features that are different from those of earlier Russian-grown hydrothermal synthetic emeralds and other colored synthetic beryls. This new type of hydrothermal synthetic is being com-

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Mr. Koivula is chief research gemologist, the late Mr. Kammerling was vice-president of research and development, Mr. DeGhionno is senior staff gemologist, and Dr. Johnson is research scientist at the GIA Gem Trade Laboratory, Santa Monica. Dr. Reinitz is research scientist at the GIA Gem Trade Laboratory, New York. Dr. Fritsch is professor of physics at the Gemology Laboratory, Physics Department, University of Nantes, France.

Acknowledgments: The authors thank Walter Barshai, director of Pinky Trading Co., Bangkok, for supplying the hydrothermal synthetic emeralds examined for this report. Sam Muhlmeister performed the EDXRF analysis, Yan Liu and Mike Moon assisted with gathering spectra, and Patricia Maddison and Philip Owens helped with the gemological testing. Dr. John Armstrong and Paul Carpenter, of the California Institute of Technology, assisted with the SEM-EDS analyses performed there.

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mercially manufactured through a joint-venture company known as Tairus. The crystals are grown by the Laboratory for Hydrothermal Growth at the Institute of Geology and Geophysics in the Siberian Branch of the Russian Academy of Sciences in Novosibirsk, Siberia. They are fashioned and released to the market in Bangkok. Comparison of these hydrothermal synthetic emeralds to those previously described shows distinct differences, particularly with respect to inclusions, although they can still be conclusively identified as synthetic.

MATERIALS AND METHODS

All the samples used for this study were obtained in Bangkok from the same lot. According to the supplier, they were manufactured in 1993. The eight transparent oval mixed cuts (figure 1) weighed between 0.17 and 0.41 ct, with measurements ranging from 4.87 × 2.96 × 1.99 mm to 5.72 × 4.15 × 2.98 mm. The body color of all eight synthetic emeralds, when examined table up, was a very slightly bluish green of medium dark tone and moderate intensity. To the unaided eye, all the samples appeared flawless.

Refractive index was determined using a Duplex II refractometer with a polarizing filter (to determine birefringence) and a sodium vapor light source. We established specific gravity by the hydrostatic method, using a Mettler AM100 electronic balance. The reaction to ultraviolet radiation was observed under darkroom conditions with a standard UV lamp. The samples were also examined with a Chelsea filter and a Hanneman-Hodgkinson emerald filter (Hodgkinson, 1995), as well as with a standard polariscope, a calcite dichroscope, and a Beck prism spectroscope.

In addition, we submitted these samples to infrared spectroscopy, X-ray fluorescence spectroscopy, and electron microscopy. Mid-infrared spectra were taken using a Nicolet 510 Fourier transform infrared spectrometer (FTIR) in the region from 6600 to 400 cm^{-1} (1515–25,000 nm), at a resolution of 4 cm^{-1}. Ultraviolet-visible-near infrared (UV-Vis-NIR) spectra were taken with a Hitachi U-4001 spectrophotometer in the region 250–2500 nm, with calcite polarizers used to obtain oriented spectra in two crystallographic directions for three faceted ovals—0.19, 0.21, and 0.37 ct.

Energy-dispersive X-ray fluorescence (EDXRF) spectroscopy was performed on four faceted ovals (0.19, 0.23, 0.37, and 0.41 ct) using a Tracor Northern (Spectrace) 5000 unit with a rhodium X-ray tube. Three faceted ovals (0.20, 0.23, and 0.41 ct) were examined using a Camscan Series II analytical scanning electron microscope (SEM) at the Division Analytical Facility, Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, operating under run conditions of 15 kV excitation voltage and 100 μA specimen current, with a Tracor Northern 5500 energy-dispersive X-ray spectrometer for elemental analyses at selected points.

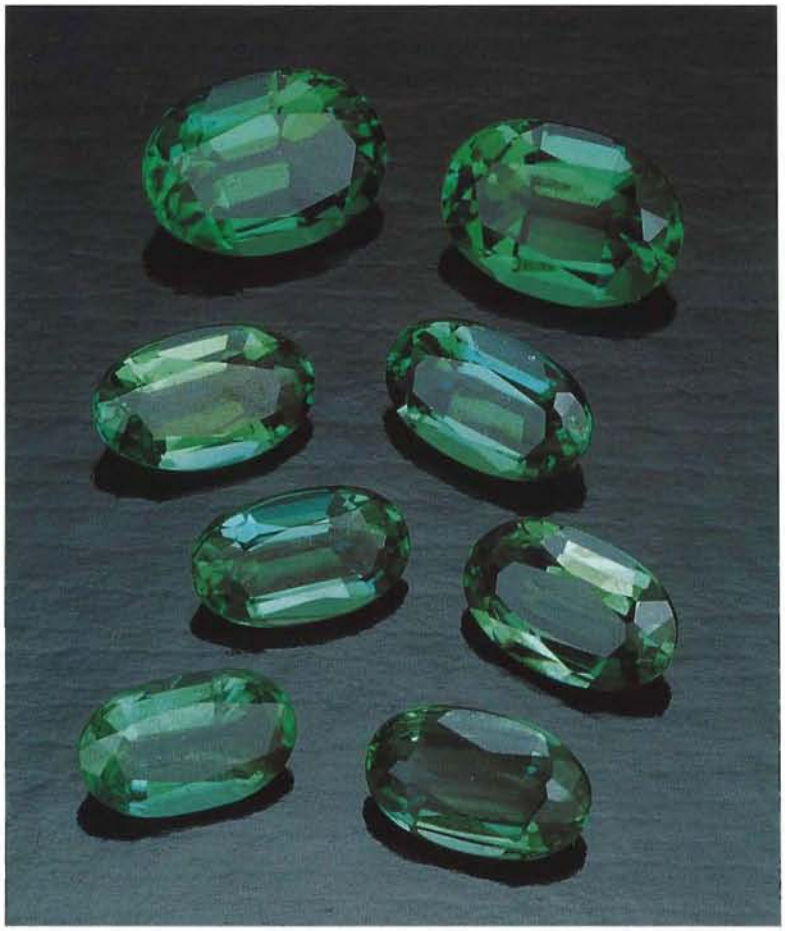


Figure 1. The eight Russian hydrothermal synthetic emeralds examined for this report, all oval mixed cuts, ranged from 0.17 to 0.41 ct. Photo by Maha DeMaggio.

GEMOLOGICAL PROPERTIES

The results of the gemological testing on this collection of Russian hydrothermal synthetic emeralds are summarized in table 1 and discussed below.

Refractive Index. We recorded R.I. ranges of 1.572–1.578 (n_ε) and 1.579–1.584 (n_o), with a bire-

fringence of 0.006–0.007 and a uniaxial negative optic character. These refractive indices are comparable to those of previously examined Russian hydrothermal synthetic emeralds (see, e.g., Koivula, 1985; Schmetzer, 1988; Henn et al., 1988; Scarratt, 1994), but they are higher than the values reported for the Biron material (Kane and Liddicoat, 1985). These values also overlap those reported for natural emeralds (Schrader, 1983).

Specific Gravity. The eight samples had average S.G. values for three tests that ranged from 2.67 to 2.73. Although the air weights were consistent for each weighing, the values obtained in water immersion were not, due to the relatively small size of these samples; this led to the variation in the final calculated S.G.'s.

These values are comparable to those previously reported for hydrothermal synthetic emeralds (Takubo, 1979; Koivula, 1985; Kane and Liddicoat, 1985; Schmetzer, 1988; Henn et al., 1988; Scarratt, 1994; "What to look for . . ," 1989). They also overlap those reported for natural emeralds (Schrader, 1983; Webster, 1994).

TABLE 1. Gemological properties of the new Russian hydrothermal synthetic emeralds.

Properties that overlap those of other synthetic and natural emeralds	
Color (through table)	Very slightly bluish green
Refractive index	n_ε = 1.572–1.578; n_o = 1.579–1.584
Birefringence	0.006–0.007
Optic character	Uniaxial negative
Specific gravity (hydrostatic)	2.67–2.73
Ultraviolet fluorescence[a]	Inert to both long- and short-wave UV
Phosphorescence	None
Chelsea color-filter reaction	Weak red
Pleochroism	Moderate yellowish green and bluish green
Optical absorption spectrum	Virtually identical to the spectrum shown by natural and earlier Russian hydrothermal synthetic emeralds
Inclusions	Opaque black hexagonal plates and crystals that look like phenakite
Possible key identifying properties	
Inclusions	Numerous tiny red-brown and white nondescript particles
Infrared spectrum	Weak to moderate absorptions at about 2235, 2320, and 2440 cm^{-1}; weak, sharp peak at about 2358 cm^{-1}; broad shoulder at 4052 cm^{-1}.

[a]*Testing done in total darkness (darkroom conditions).*

Reaction to Ultraviolet Radiation. As with natural emeralds and other hydrothermal synthetic emeralds reported in the literature, all of the samples were inert to long-wave (365 nm) and short-wave (254 nm) UV radiation.

Color-Filter Reactions. When placed on the tip of a fiber-optic illuminator and observed through the Chelsea color filter at a low angle to the direction of illumination, all eight samples revealed a weak red glow. These stones also showed a very weak red transmission luminescence in white light when no filter was used. (The angle of observation is important, and the only visible light source in the room should be the fiber-optic illuminator.) Similar reactions have been observed in both natural and synthetic emeralds. Like natural emerald, these synthetics showed no reaction to the Hanneman-Hodgkinson emerald filter.

Polariscope Reaction. Each stone exhibited typical double refraction and standard uniaxial optic figures. Because of facet interference, we had to immerse the three smallest stones in methylene iodide to observe their optic figures.

Dichroism. All eight specimens showed distinct dichroism of yellowish green (perpendicular to the optic axis) and bluish green (parallel to the optic axis), as is typical of many natural and synthetic emeralds. No specific optic orientation was noted in the eight samples.

Spectroscopy. Using both transmitted and internally reflected light, we observed a relatively weak absorption spectrum in all eight stones, but it was typical of emerald (Liddicoat, 1987). The features noted were located in the red at approximately 652 (weak), 632 (moderate), and 606 (moderate) nm. In addition, there was a weak, "smudged" band of general absorption in the orange-red between 584 and 603 nm, and a cutoff in the red starting at about 660 nm.

Internal Characteristics. The most obvious characteristic seen with the microscope (with any illumi-

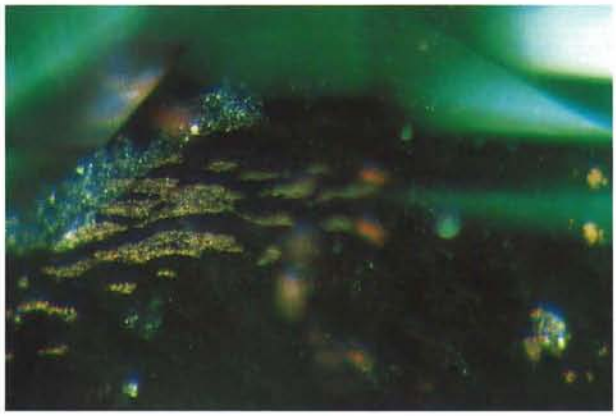


Figure 2. Clouds of tiny red-brown particles, like those shown here, were seen in all eight of the new Russian hydrothermal synthetic emeralds examined. They have not been reported before in natural or other hydrothermal synthetic emeralds. Photomicrograph by John I. Koivula, magnified 50×.

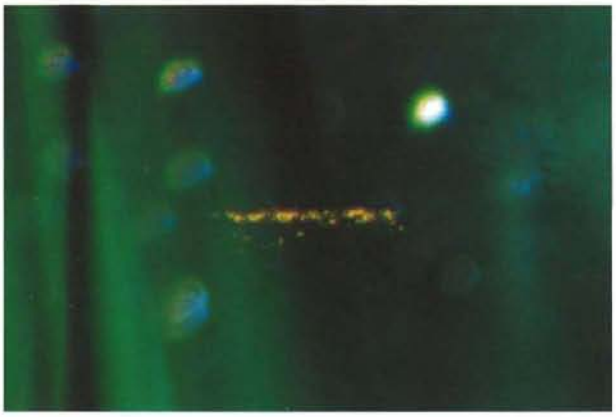


Figure 3. In one of the Russian synthetics, the tiny red-brown particles appeared in a linear arrangement. Photomicrograph by John I. Koivula, magnified 50×.

nation technique, in all eight samples) was the lack of the distinctive and highly developed chevron- or V-shaped growth zoning that is typical of all other Russian hydrothermal synthetic beryls (Takubo, 1979; Koivula, 1985; Gübelin and Koivula, 1986; Schmetzer, 1988; Henn et al., 1988). Also, the internal motif observed in these new hydrothermal synthetics does not resemble the suite of characteristic inclusions recognized so far in natural emeralds (Gübelin and Koivula, 1986; Schwarz, 1987). These unusual internal characteristics serve to identify them as a new type of Russian hydrothermal synthetic.

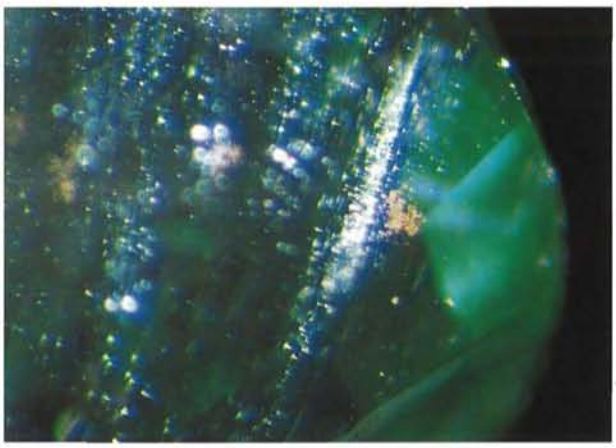
Specifically, all eight stones contained numerous tiny red-brown particles (visible even at 10× in some cases), which were so small that they could not be resolved microscopically into any recognizable crystal habit (even at 120×). These particles usually were arranged in dense clouds with no particular orientation or form (figure 2); in one instance, they appeared in a linear arrangement (figure 3).

With fiber-optic illumination and 30× magnification, we also saw clouds and layers of tiny, randomly oriented, white-appearing particles in all eight of the synthetic emeralds. These inclusions were extremely dense (figure 4) and easily observed in four of the eight samples, but they were very difficult to detect in the other four, even with strong pinpoint fiber-optic illumination. As with the red-brown inclusions, these white-appearing particles were too small to be resolved completely with a standard gemological microscope. Because of their small size, their white appearance may be due in part to light reflection and scattering rather than to their true color.

One 0.20 ct stone had a small fingerprint-like accumulation of white particles under the table facet that resembled a partially healed fracture (figure 5). This was the only evidence of fracturing or fracture healing noted.

Only two samples contained inclusions large enough to be identified as crystals. One 0.37 ct sample contained a 0.2-mm-long, birefringent, euhedral crystal that had the habit of phenakite (figure 6). The 0.23 ct sample contained two opaque black hexagonal plates that showed a silvery gray metallic luster in reflected light. One of these

Figure 4. Dense concentrations of extremely fine, white-appearing particles are another distinctive internal feature noted in the new Russian hydrothermal synthetic emeralds. Photomicrograph by John I. Koivula, magnified 30×.



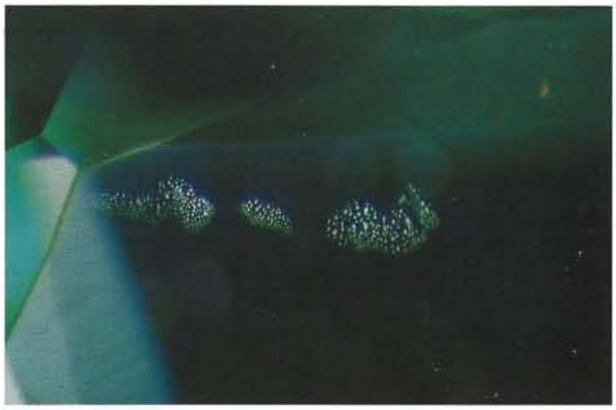


Figure 5. Only one fingerprint-like pattern was observed in any of the eight samples of Russian synthetic emeralds. Photomicrograph by John I. Koivula, magnified 35×.

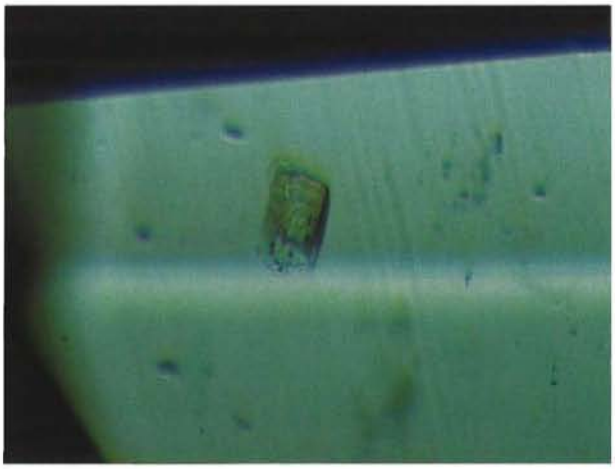
hexagonal plates (figure 7) caused growth blockage in the form of two conical growth zones extending away from one flat surface, which was visible in shadowed transmitted light.

ADVANCED TESTING

Infrared Spectroscopy. Features due to water and hydroxides are easily seen in the infrared spectra of emeralds and other beryls, and are useful in differentiating natural stones from their synthetic counterparts (Wood and Nassau, 1968; Schmetzer and Kiefert, 1990). Absorption features from other chemical groups (such as CO_2) are also present.

The mid-infrared spectra of our eight samples are similar in overall appearance to those of natural emeralds and other Russian hydrothermal emeralds, but they differ significantly from those of both flux and other (non-Russian) hydrothermal synthetic emeralds (figure 8). Other hydrothermal synthetic emeralds have high water contents and, thus, very strong absorptions in the region around 3600 cm^{-1} as well as strong absorptions between 3000 and 2000 cm^{-1}. However, these Russian hydrothermal synthetic emeralds have only moderate to strong water-related peaks at 3600 cm^{-1} and are quite transparent at 3000 cm^{-1}. Nevertheless, such a spectrum still contrasts sharply with that of a flux-grown synthetic emerald, which is essentially free of water.

Figure 6. This 0.2-mm-long crystal, seen in the 0.37 ct Russian hydrothermal synthetic emerald, looks like phenakite. Photomicrograph by John I. Koivula.



Wood and Nassau (1968) described two positions that water molecules can occupy within the channels in a beryl's structure. The different orientations of these "type I and type II water" molecules are clearly reflected in the positions of their absorption peaks in the ordinary- versus extraordinary-ray spectra. Both types of water cause several sharp absorption peaks between 3510 and 3825 cm^{-1}; however, only type II water causes absorptions at about 3910 cm^{-1} and 3230 cm^{-1}. Wood and Nassau found that all natural emeralds and Linde hydrothermal synthetic emeralds contained type I water, but that only natural emeralds showed type II water, although in greatly varying amounts. In 1990, however, Schmetzer and Kiefert reported type II water bands in Lechleitner and some Russian hydrothermal synthetic emeralds as well.

Because of the difficulties inherent in taking the spectra of faceted gems, we could only obtain unoriented mid-infrared spectra for our samples, which made the interpretation of mid-infrared water bands more difficult. Weak type II peaks can be seen in the spectra of both the natural emerald and the representative Russian hydrothermal synthetic emerald from our study sample, as shown in figure 8.

The gross spectral similarities in the mid-infrared between these Russian hydrothermal emeralds and natural emeralds do not extend to the finer structure seen in the region around 2300 cm^{-1} (figure 9A). Natural emeralds have a moderate to strong, sharp absorption at 2358 cm^{-1}, much stronger in the ordinary-ray spectrum, which Wood and Nassau assign to CO_2 oriented within the beryl structure. Stockton (1987) describes a distinct peak at 2290 cm^{-1} and a peak or shoulder at about 2340 cm^{-1}, in addition to the peak at 2358 cm^{-1} (which she asserts is always stronger than the 2340 cm^{-1} in natural emeralds), but she does not identify the causes of these absorptions. All three features also have been observed in the

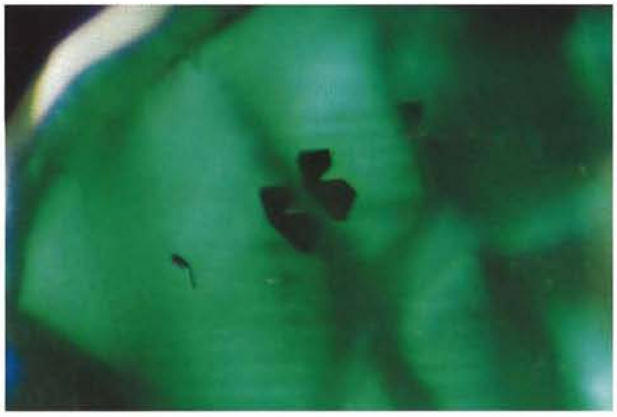


Figure 7. One of the samples contained two black opaque hexagonal plates like this one, here multiply reflected by facets. Photomicrograph by John I. Koivula, magnified 50×.

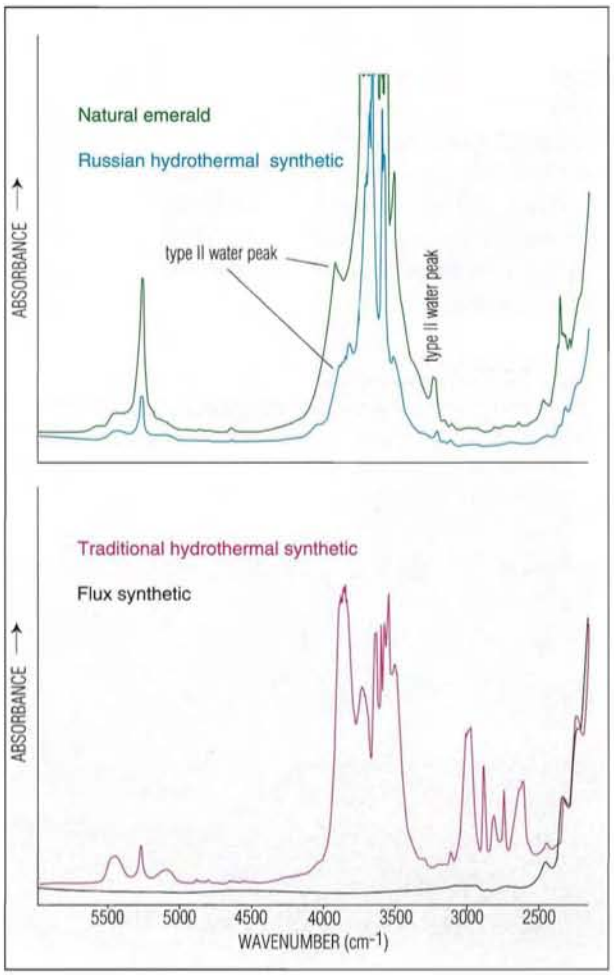
spectra of 67 natural emeralds identified by standard gemological techniques in the GIA Gem Trade Laboratory over the last four years. Although these peaks vary considerably in magnitude from one spectrum to another, probably due in part to the fact that these are unoriented spectra, our data support Stockton's statement regarding their relative strengths in natural emeralds.

In this region around 2300 cm^{-1}, however, our eight Russian hydrothermal synthetic emeralds showed a structure very different from that seen for natural emeralds. These synthetics have weak to moderate, somewhat broad absorptions at about 2235, 2320, and 2440 cm^{-1}, and a weak, sharp peak at about 2358 cm^{-1}. They show no peak at 2290 cm^{-1}. Accepting Stockton's assertion that the "2340 cm^{-1}" band may be found as far away as 2310 cm^{-1} in synthetic emeralds, we see that in these Russian hydrothermal synthetics, too, the "2340" peak (actually at 2320 cm^{-1} for our samples) is stronger than the absorption at 2358 cm^{-1}.

Stockton's examination of three Russian hydrothermal emeralds available at that time also revealed weak features at 4375 cm^{-1} and 4052 cm^{-1}, which had not been seen in natural emeralds. The spectra of the Russian synthetic emeralds examined for this study have no features at 4375 cm^{-1}, but all show a broad shoulder at 4052 cm^{-1} (figure 9B).

Water in beryl also absorbs in the near-infrared at about 1400 and 1900 nm, and in these regions we were able to obtain oriented spectra for three samples. The extraordinary-ray near-infrared spectra (figure 10A) of a natural emerald and all three synthetics showed strong water-related peaks at about 1896 nm and 1400 nm, a moderate peak around 1464 nm, and weak peaks at 1149 nm and 2145 nm. In the ordinary-ray spectra (figure 10B), there are three strong peaks at 1950, 1895, and 1830 nm, and two moderate peaks around 1400 nm. Comparison of these results with Wood and Nassau's figure 4 confirms that both the natural emerald used for reference and these Russian hydrothermal synthetic emeralds contain small amounts of type II water, similar to Schmetzer and Kiefert's "group II" emeralds.

Figure 8. Representative mid-infrared spectra of a natural emerald, a "traditional" hydrothermal synthetic emerald, a flux synthetic emerald, and one of the new Russian hydrothermal synthetic emeralds are shown here for comparison. Note that the spectrum of the Russian hydrothermal synthetic is more like that of the natural emerald than like that of either the typical hydrothermal synthetic or the flux synthetic.



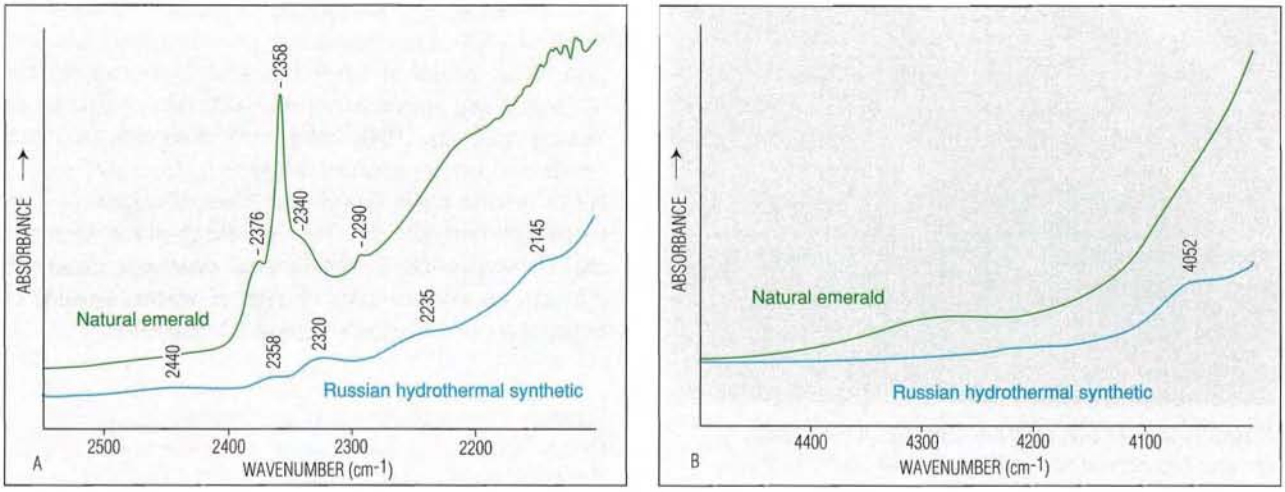


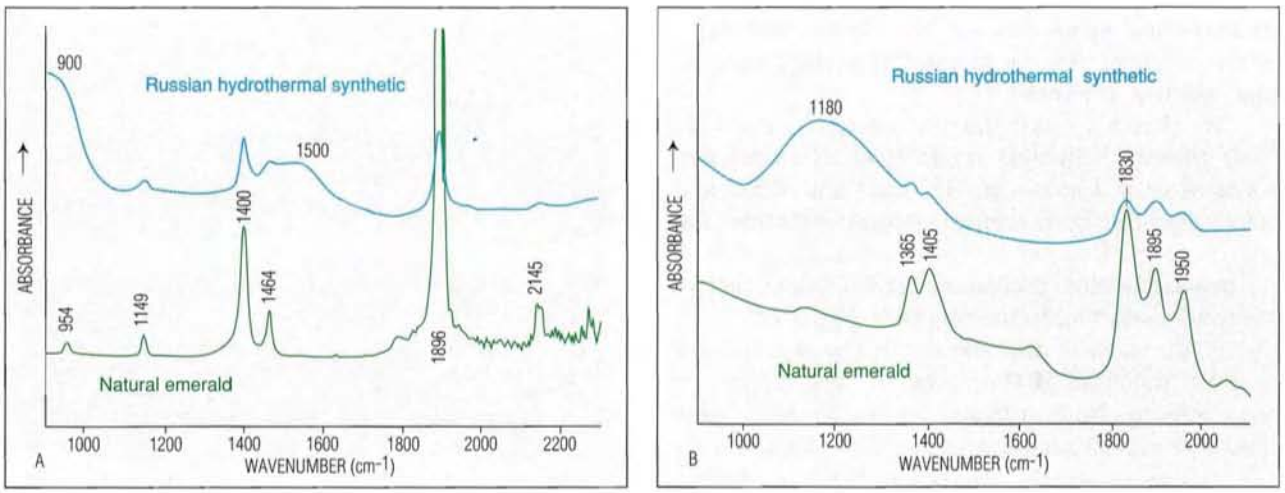
Figure 9. (A) The fine structure of their spectra around 2300 cm^{-1} (mid-infrared) reveals marked differences between natural emerald (green curve) and the Russian hydrothermal synthetic emeralds tested for this study (blue curve). (B) In the region around 4200 cm^{-1}, these synthetics display one of the features reported by Stockton (1987) for other Russian hydrothermal synthetics, at 4052 cm^{-1}. Such a shoulder has not been seen in natural emeralds.

There are, however, some dramatic differences in the near-infrared spectra of these Russian (manufactured by Tairus) synthetic emeralds as compared to those of natural stones. The synthetic emeralds produced two broad absorptions in the extraordinary-ray spectrum (figure 10A), one centered around 1500 nm and the other at about 900 nm, and one in the ordinary-ray spectrum (figure 10B) at about 1180 nm; none of these features has been reported in natural emeralds.

Thus, in both the mid- and near-infrared, even for unoriented spectra, these Russian hydrothermal synthetic emeralds display diagnostic features that distinguish them from all natural emeralds.

Ultraviolet-Visible Spectroscopy. The UV-Vis absorption spectra of all eight Russian hydrothermal synthetic emeralds studied showed comparable features, which are similar to those published by Schmetzer (1988) for Russian hydrothermal syn-

Figure 10. These near-infrared extraordinary-ray (A) and ordinary-ray (B) spectra of a natural emerald (green curve) and a sample new Russian hydrothermal synthetic emerald (blue curve) show that both contain small amounts of type II water, which was once believed to occur only in natural emeralds. Note, however, the broad absorption peaks in the synthetic that are not seen in the natural stone.



thetic emeralds. The green color is due to a transmission window around 500 nm, surrounded by two broad absorptions centered at about 435 and 600 nm. These measurements are in partial disagreement with handheld spectroscope observations. For example, the lines observed at 632 and 652 nm with the spectroscope are probably those noted at 637 and 661 nm with the spectrometer.

Chemical Analysis. *EDXRF.* Four of the synthetic emeralds were selected for EDXRF analysis. Only some of the elements present in emerald are detectable by X-ray fluorescence; oxygen, hydrogen, and beryllium are not. In addition to aluminum and silicon, a minor amount of iron and traces of chromium, potassium, calcium, titanium, nickel, and copper were detected in the four faceted stones. Unlike some other (non-Russian) hydrothermal synthetic emeralds (see, e.g., Hänni and Kiefert, 1994), our samples did not show any chlorine.

SEM-EDS. In an effort to identify the minute white and red-brown particles in these synthetic emeralds, we submitted three samples to SEM-EDS analysis. Only one white-appearing inclusion, in a 0.20 ct sample, reached the surface. Within this inclusion, we found a micron-sized calcium- and sulfur-bearing grain—possibly synthetic gypsum. Traces of sodium, potassium, titanium, iron, and chlorine—found in the dark pit on the emerald's surface—may be the evaporated residue of the hydrothermal solution in which the emerald grew, or may represent residue from the polishing compound.

CONCLUSION

These eight Russian synthetic emeralds represent a new type of hydrothermal product. Their standard gemological properties, such as R.I. and S.G., overlap those of both natural and other hydrothermal synthetic emeralds. However, microscopy and spectroscopy provide information useful for gemological identification.

Although the roiled, chevron-shaped growth zoning that is generally considered to be characteristic of Russian synthetic beryls was absent in this new product, other internal characteristics, if present, would readily identify this material as synthetic. In particular, the tiny red-brown particles (of undetermined nature) observed in all eight faceted ovals have not been previously noted in natural emeralds or in the "traditional" Russian hydrothermal product. In the absence of such particles, advanced testing by such techniques as infrared spectroscopy or EDXRF analysis may be needed to identify this material conclusively as a synthetic.

REFERENCES

Gübelin E.J., Koivula J.I. (1986) *Photoatlas of Inclusions in Gemstones*, ABC Edition, Zurich, Switzerland.

Hänni H.A., Kiefert L. (1994) AGEE hydrothermal synthetic emeralds. *JewelSiam*, October/November, pp. 80–85.

Henn U., Lind T., Bank H. (1988) Hydrothermally grown synthetic emeralds from USSR. *Canadian Gemmologist*, Vol. 9, No. 3, pp. 66–72.

Hodgkinson A. (1995) The Hanneman-Hodgkinson synthetic emerald filter. *Canadian Gemmologist*, Vol. 16, No. 1, pp. 18–22.

Kane R.E., Liddicoat R.T. Jr. (1985) The Biron hydrothermal synthetic emerald. *Gems & Gemology*, Vol. 21, No. 3, pp. 156–170.

Koivula J.I. (1985) Gem news: More on Russian hydrothermal synthetic emeralds. *Gems & Gemology*, Vol. 21, No. 1, p. 59.

Liddicoat R.T. Jr. (1987) *Handbook of Gem Identification*, 11th ed. Gemological Institute of America, Santa Monica, CA.

Nassau K. (1980) *Gems Made by Man*. Chilton Book Co., Radnor, PA.

Scarratt K. (1994) Lab report: Hydrothermal synthetic emerald. *JewelSiam*, Vol. 5, No. 1, pp. 67–68.

Schmetzer K. (1988) Characterization of Russian hydrothermally-grown synthetic emeralds. *Journal of Gemmology*, Vol. 21, No. 3, pp. 145–162.

Schmetzer K., Kiefert L. (1990) Water in beryl: a contribution to the separability of natural and synthetic emeralds by infrared spectroscopy. *Journal of Gemmology*, Vol. 22, No. 4, pp. 215–223.

Schrader H.W. (1983) Contributions to the study of the distinction of natural and synthetic emeralds. *Journal of Gemmology*, Vol. 18, No. 6, pp. 530–543.

Schwarz D. (1987) *Esmeraldas: Inclusões em Gemas*. Escola de Minas, Universidade Federal de Ouro Preto, Ouro Preto, Brazil.

Stockton C.M. (1987) The separation of natural from synthetic emeralds by infrared spectroscopy. *Gems & Gemology*, Vol. 23, No. 2, pp. 96–99.

Takubo H. (1979) Characteristics of synthetic hydrothermal emeralds from USA and USSR. *Journal of the Gemmological Society of Japan*, Vol. 6, No. 4, pp. 3–4.

Webster R. (1994) *Gems: Their Sources, Descriptions and Identification*, 5th ed. Revised by Peter Read, Butterworths, London.

What to look for in Vasar synthetic emeralds (1989). *Jewellery News Asia*, September, pp. 178–179.

Wood D.L., Nassau K. (1968) The characterization of beryl and emerald by visible and infrared absorption spectroscopy. *American Mineralogist*, Vol. 53, No. 5-6, pp. 777–799.

GROWTH METHOD AND GROWTH-RELATED PROPERTIES OF A NEW TYPE OF RUSSIAN HYDROTHERMAL SYNTHETIC EMERALD

By Karl Schmetzer

A new type of Russian hydrothermal synthetic emerald is produced by seeded growth in steel autoclaves without noble-metal inserts; the seed slices have been cut parallel to a face of the second-order hexagonal dipyramid s *{1121}. This seed orientation avoids the easily recognizable growth pattern seen in earlier Russian production. However, characteristic growth planes of a different nature—that is, parallel to* s *and forming a 45° angle with the optic axis—are present in the new material.*

Hydrothermally grown synthetic emeralds from Russia have been discussed in the gemological literature since 1983. Gemological, chemical, and spectroscopic properties of these synthetic emeralds were comprehensively described by Schmetzer in 1988. Production methods were also detailed. The most noteworthy features of this older manufactured material are:

- Normal chromium, high iron, and (unlike other synthetic or natural emeralds) measurable amounts of nickel and copper.
- Absorption bands of Cr^{3+}, Fe^{3+}, Ni^{3+}, and Cu^{2+} in the visible and near-infrared, with chromium and nickel as dominant color-causing trace elements.
- Absorption bands of type I and type II water molecules in the infrared.
- Series of parallel growth lines with a step-like microstructure, which are occasionally connected to color zoning (figure 1), revealing an inclination of 30°–32° vis à vis the optic axis of the samples.

Details of the production technique explain why these properties were unique for commercially produced synthetic emerald. Specifically, seed slices oriented parallel to a second-order hexagonal dipyramid {5 5 $\overline{10}$ 6} or its symmetric equivalent are placed in steel autoclaves without noble-metal inserts. With this seed orientation (for that of other commercial producers, see Kiefert and Schmetzer, 1991), extremely fast growth can be obtained (Klyakhin et al., 1981; Lebedev and Askhabov, 1984; Lebedev et al., 1986).

The crystal form {5 5 $\overline{10}$ 6} has not been observed in natural beryl (see Goldschmidt, 1897), because crystal faces generally correspond to the directions of slow growth. As a consequence of the rapid growth of the early Russian hydrothermal synthetics, however, a distinct step-like microstructure is produced parallel to the seed surface, and subindividuals of synthetic emerald are found

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Gems & Gemology, Vol. 32, No. 1, pp. 40–43.

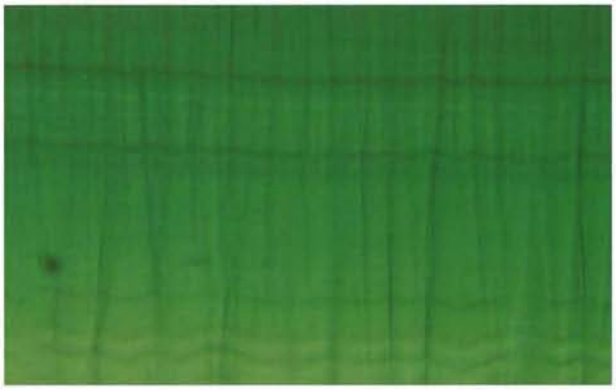

Figure 1. The earlier production of Russian hydrothermal synthetic emerald shows step-like growth lines and color zoning, as well as irregularly changing subgrain boundaries between subindividuals that are almost perpendicular to the color zoning. Crossed polarizers, immersion, magnified 45×.

Figure 2. Also in the earlier production of Russian hydrothermal emerald, boundaries between subindividuals appear as an angular growth pattern. Immersion, magnified 45×.

with a preferred orientation oblique to the seed plate (figure 1). The boundaries between these subindividuals are characterized by angular growth patterns (figure 2), which are also easily recognizable with a microscope.

Because of these characteristic growth features, such Russian hydrothermally grown synthetic emeralds can be distinguished easily from their natural counterparts by microscopic examination. Additional techniques, such as spectroscopy or X-ray fluorescence, are rarely necessary.

An apparently new type of Russian hydrothermally grown synthetic emerald was first mentioned by Scarratt (1994) and is comprehensively described by Koivula et al. in this issue (1996). This new material does not show the distinct growth pattern of the previous material, although the gemological, spectroscopic, and chemical properties were similar to that of the older type. This article describes the unusual growth pattern of this newer material and suggests the changes in growth technique that have caused it.

MATERIALS AND METHODS

In November 1995, the author purchased eight "rough" samples of this new type of Russian synthetic emerald in Bangkok, where they were offered as a new type of internally "clean" synthetic emerald. All samples were fragments or slices of what were originally larger synthetic emerald crystals. Two contained residual portions of colorless (figure 3) or slightly greenish seeds. One of the samples had small external crystal faces, which were identified as prisms $\{10\bar{1}0\}$ and $\{11\bar{2}0\}$ in combination with a face of the hexagonal dipyramid s $\{11\bar{2}1\}$.

Four additional faceted samples were made available by colleagues from GIA, part of the sample described in Koivula et al. (1996). Because the gemological properties of the eight rough samples were consistent with the material described in the Koivula et al. article, the reader is referred to that comprehensive description for additional information.

The internal growth structures of these samples were characterized by means of a Schneider horizontal (immersion) microscope with a specially designed sample holder and with specially designed

Figure 3. In this sample of the new type of Russian hydrothermal emerald, we can see a colorless seed plate and growth zoning parallel to the seed/synthetic emerald boundary at a 45° angle to the c-axis. Crossed polarizers, immersion, magnified 16×.

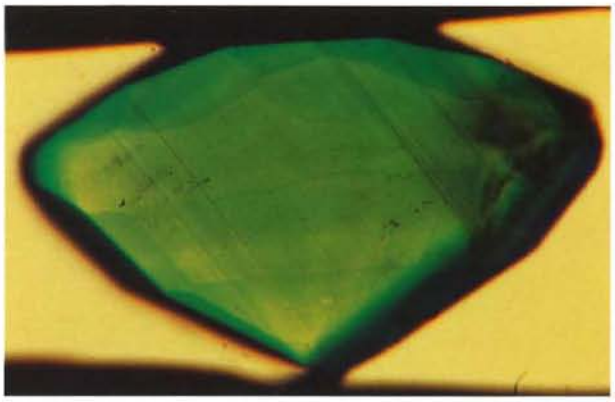

Figure 4. A pattern of growth planes parallel to the hexagonal dipyramid s *can be seen intersecting the c-axis at an angle of 45° in this new type of Russian hydrothermal emerald. Immersion, magnified 25×.*

(to measure angles) eyepieces. For more on the techniques used to determine growth structures, refer to Box A of Peretti et al. (1995, p. 8).

RESULTS

Energy-dispersive X-ray fluorescence (EDXRF) analysis and absorption spectroscopy revealed the presence of chromium, iron, nickel, and copper as trace elements, which is consistent with known data on the earlier material; the infrared spectra were also similar to those seen for the earlier product (see, e.g., Schmetzer, 1988). All of these properties indicate that the new material is still produced by seeded growth in steel autoclaves without noble-metal liners. That is, the copper and nickel (and high iron) originate at least partly from the walls of the autoclave, and would not be evident if a noble-metal liner (a more expensive technique) were used.

The two samples that retained seed residue revealed distinct growth zoning consisting of one series of planar growth faces parallel to the seed/synthetic emerald boundary (figure 3). All other rough and faceted samples showed a similar series of parallel growth planes (figure 4). In all 12 samples examined, these dominant growth patterns formed an approximately 45° angle with the optic axes of the emerald crystals. These measurements indicate an orientation of the seeds parallel to a face of the second-order hexagonal dipyramid *s* $\{11\bar{2}1\}$. In addition to the distinctive growth pattern parallel to *s*, the rough sample with prism faces showed small areas with subordinate growth zoning parallel to both prisms $\{10\bar{1}0\}$ and $\{11\bar{2}0\}$. One faceted sample had growth zoning parallel to one prism face in a small growth area, too. These two samples probably came from the growth area of a synthetic crystal that was confined to the upper or lower end of the respective seed. No growth pattern similar to that of the older material was observed.

Hydrothermally grown synthetic emeralds of other producers, in general, also reveal only one dominant orientation of growth planes relative to the respective seed, the angles of which are summarized in table 1. Note the significantly greater angle for the new Russian material. By comparison, natural emeralds typically show more than one orientation of growth planes, and they are different from those seen in these hydrothermal synthetics. In particular, *s* faces in natural emeralds will normally occur in combination with prism faces, with a basal pinacoid, and with other hexagonal dipyramids, but not as a single and dominant growth plane (see Kiefert and Schmetzer, 1991).

DISCUSSION

Experiments with hydrothermal emerald synthesis have shown that growth rates perpendicular to *s* $\{11\bar{2}1\}$ are somewhat slower than growth rates perpendicular to $\{5\ 5\ \bar{1}0\ 6\}$. By using seed slices cut parallel to *s*, however, good growth rates can still be obtained (Klyakhin et al., 1981; Lebedev and Askhabov, 1984; see also Flanigen, 1971; Flanigen and Mumbach, 1971), and the resulting material lacks the easily recognizable growth pattern of the older material.

TABLE 1. Orientation of seeds and dominant growth planes in hydrothermally grown synthetic emeralds.[a]

Producer or trade name	Inclination of seed and/or growth planes versus the optic axis
Linde	36°–38°
Regency	38°
Lechleitner	32°–40°
Biron	22°–23°
Pool	22°–24°
AGEE	19°–21°
Swarovski	0°
Russian (old)	30°–32°
Russian (new)	43°–47°

[a]*From Kiefert and Schmetzer, 1991, and author's files (based on examination of at least 10 samples for each product). Note that each producer normally used only one specific orientation. Even hydrothermal synthetic emeralds distributed under different names (e.g., Linde and Regency) can be shown from the orientation of their seeds, vis à vis the c-axis of the beryl crystals, to be products of the same manufacturing technique.*

The recognition of one dominant growth pattern parallel to *s* in an emerald of doubtful origin is of diagnostic value as an indication that it may be synthetic. Further diagnostic techniques (e.g., absorption spectroscopy and/or EDXRF) should be used to confirm or disprove such a preliminary result. This is due to the possible presence of *s* faces in natural emerald.

REFERENCES

Flanigen E.M. (1971) Hydrothermal process for growing crystals having the structure of beryl in an alkaline halide medium. United States Patent No. 3,567,642, issued March 2, 1971.

Flanigen E.M., Mumbach N.R. (1971) Hydrothermal process for growing crystals having the structure of beryl in an acid halide medium. United States Patent No. 3,567,643; issued March 2, 1971.

Goldschmidt V. (1897) *Krystallographische Winkeltabellen.* Verlag von Julius Springer, Berlin, pp. 65–66.

Kiefert L., Schmetzer K. (1991) The microscopic determination of structural properties for the characterization of optical uniaxial natural and synthetic gemstones. Part 2: Examples for the applicability of structural features for the distinction of natural emerald from flux-grown and hydrothermally-grown synthetic emerald. *Journal of Gemmology*, Vol. 22, No. 7, pp. 427–438.

Koivula J.I., Kammerling R.C., DeGhionno D., Reinitz I., Fritsch E., Johnson M.L. (1996) Gemological investigation of a new type of Russian hydrothermal synthetic emerald. *Gems & Gemology*, Vol. 32, No. 1, pp. 32–39.

Klyakhin V.A., Lebedev A.S., Il'in A.G., Solntsev V.P. (1981) Growing of hydrothermal beryl. *Sintez i Vyrashchivanie Optich. Kristallov i Yuvelir, Kamnei*, Novosibirsk, pp. 45–66 [in Russian].

Lebedev A.S., Askhabov A.M. (1984) Regeneration of beryl crystals. *Zapiski Vsesoyuznogo Mineralogicheskogo Obshchestva*, Vol. 113, No. 5, pp. 618–628 [in Russian].

Lebedev A.S., Il'in A.G., Klyakhin V.A. (1986). Hydrothermally-grown beryls of gem quality. In *Morphology and Phase Equilibria of Mineral*, Proceedings of the 13th General Meeting of the International Mineralogical Association, Varna 1982, Vol. 2, publ. Sofia, pp. 403–411 [in Russian].

Peretti A., Schmetzer K., Heinz-Jürgen B., Mouawad F. (1995) Rubies from Mong Hsu. *Gems & Gemology*, Vol. 31, No. 1, pp. 2–26.

Scarratt K. (1994) Lab report from the Asian Institute of Gemological Sciences (AIGS). *JewelSiam*, Vol. 5, No. 1, pp. 62–69.

Schmetzer K. (1988) Characterization of Russian hydrothermally-grown synthetic emeralds. *Journal of Gemmology*, Vol. 21, No. 3, pp. 145–164.

GIA GEM TRADE

LAB NOTES

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A Notable Yellow Synthetic DIAMOND from Russia

At one of the trade shows in the Far East last fall, a diamond dealer and manufacturer showed a tray of about two dozen small, yellow, faceted synthetic diamonds with a sign suggesting that every gemologist should buy one for reference. The 0.23 ct yellow round brilliant shown in figure 1 was obtained at that show and examined in both the East and West Coast labs. The dealer offering these synthetics said that they were grown in Russia, and we found that the properties of this sample were consistent with those reported previously for such material (see, e.g., the comprehensive article on Russian synthetic diamonds by J. E. Shigley et al., *Gems & Gemology*, Winter 1993, pp. 228–248). However, this stone differs a little from other Russian synthetic diamonds reported in the literature with regard to the graining and color zoning.

Note in particular the geometric arrangement of the brown graining illustrated in figure 2. This series of concentric squares bears some similarity to the phantom graining sometimes seen through the table of a "4-point" natural diamond—that is, one made by sawing a regular octahedron along the cubic direction into two parts, each of which is then polished. In this instance, however, the pattern is seen when the sample is viewed from an oblique profile, a position in which a "4-point" diamond would show intersecting octahedral planes. Furthermore, when the synthetic diamond was turned 90° in profile view (figure 3), we saw an array of concentric angles (perhaps corners) connected by a thick swath of brown color, with a second group of angles slightly offset from the first. Such a pattern is unlike anything we have seen in a natural diamond.

Figure 1. This 0.23 ct round brilliant synthetic diamond, reportedly from Russia, was purchased at a trade show in the Far East.

Confirmation that these growth patterns are typical of those seen in synthetic diamond was found in the pattern of luminescence to long-wave ultraviolet radiation. Figure 4 shows a central square marking cubic sectors, with extensions from the four corners, along the dodecahedral sectors. A similar pattern was evident in the green luminescence to strong visible light. This is another example of the importance of examining a stone thoroughly, from many angles, and testing for several properties before reaching a conclusion as to its identity.

IR

EMERALD Earrings, One Natural and One Imitation

Synthetic emerald is by far the most common substitute for natural emerald that we encounter in the laboratory. This is not surprising, as both flux-grown and hydrothermally grown synthetic emeralds are readily available and aggressively marketed in the trade. However, we occasionally encounter a number of less sophisticated, if not less ingenious, simulants. These include dyed beryl (Winter 1981 Gem Trade Lab Notes, pp. 227–228), bezel-set colorless quartz with a green backing (Winter 1984 Lab Notes, pp. 228–229), and synthetic spinel and glass triplets (Winter 1986 Lab Notes, pp. 236–238).

Recently, the West Coast laboratory received a pair of yellow and white metal earrings for identification of the green emerald cuts (figure 5). The stone in the earring on the right in figure 5, which measured 8.30 × 7.80 × 5.25 mm, had properties consistent with natural emerald: R.I., 1.575–1.582; birefringence, 0.007; uniaxial negative; inert to both long- and short-wave ultraviolet radiation (although under the long-wave UV lamp there was some yellow fluorescence from surface-reaching fractures); and two- and three-phase inclusions, as well as growth and color zoning. Magnification also revealed residue from clarity enhancement. This stone was, therefore, identified as a natural

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

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emerald, with a note in the report's conclusion stating that evidence of clarity enhancement was present.

The green emerald cut in the other earring (9.25 × 7.05 × 4.05 mm) was similar in color and transparency. However, a refractive index taken on the crown produced readings of 1.545–1.552. Examination with magnification revealed that the item was assembled, consisting of an essentially colorless crown and pavilion joined at the girdle plane by a green cement (figure 6). The crown looks green because of the reflection of the green cement, which is also refracted so that it appears as a green band in the pavilion. Because of the mounting, we could not identify the material used for the pavilion; however, we did note that it contained a large partially healed fracture and two-phase inclusions (reminiscent of the internal features found in beryl of pegmatitic origin). On the basis of this examination, we identified this emerald cut as a triplet consisting of a rock crystal quartz crown joined by green cement to a pavilion of undetermined identity.

While it is possible that the pavilion was also quartz (quartz triplets, known as soudé [soldered] emeralds, were a popular emerald substitute in the early 1900s), our staff gemologists have also examined triplets that were constructed of quartz crowns/beryl pavilions and beryl crowns/quartz pavilions. We suspect that two different gem materials were not intentionally used for such stones; rather, they were fabricated from readily available, relatively inexpensive parcels of rough that included both quartz and beryl.

RCK and SFM

Figure 2. The brown graining in the synthetic diamond in figure 1 marks the cubic growth sectors. When examined from an oblique profile view with diffused transmitted light, this graining forms a pattern of concentric squares that could be confused with the phantom graining seen in some natural diamonds. Magnified 10×.

Figure 3. From another angle, the graining seen in this synthetic diamond shows a pattern closer to what has been reported previously in Russian synthetic diamonds, and unlike anything one would see in a natural diamond. Magnified 30×.

GROSSULAR Garnet–Bearing Rock, Resembling Impregnated Jadeite

We have reported before about rocks composed of garnet and other minerals that at first glance resemble jadeite jade. Recent examples include: massive grossular garnet (Winter 1991 Lab Notes, pp. 249–250), a feldspar-garnet snuff bottle (Spring 1994 Lab Notes, pp. 42–43), and grossular-diopside rock (Fall 1994 Lab Notes, p. 186). In August 1995, the West Coast laboratory received for identification several examples of another grossular garnet–bearing rock that resembled jadeite jade in a new way.

The material had the following gemological properties: color—mottled green and white, or a mottled green; optic character—aggregate; spot refractive index—1.73; fluorescence—

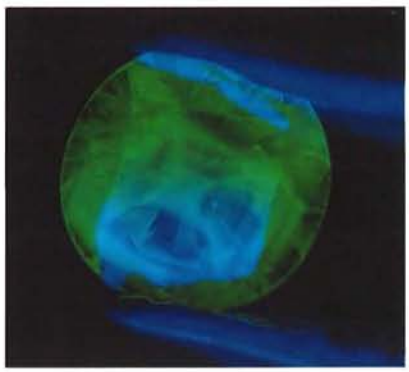


Figure 4. When exposed to long-wave UV radiation, the synthetic diamond in figure 1 showed a fluorescence pattern typical of that seen in synthetic diamonds: a square with extensions from the four corners.

inert to faint yellowish green to long-wave UV radiation, no fluorescence to short-wave UV; and weak 470 and 600 nm bands seen with the hand-held spectroscope. S.G. could not be determined because all the pieces were mounted. As these properties were not sufficient to identify the material, we also took X-ray powder diffraction patterns. One indicated that the bulk of the material was grossular garnet.

Magnification revealed why this material could be confused with jadeite jade: When observed with reflected light, the grossular stood out against the softer undercut areas of white to near-colorless material (figure 7). At first glance, this texture could be confused with that of some polymer-impregnated jadeite jade, or some other plastic-filled rock where the softer plastic also undercuts (see, for instance, "Jadeite Jade: Bleached and Impregnated, with Distinctive Surface Features," Winter 1994 Lab Notes, pp. 266–267). However, the softer material did not react to the thermal reaction tester ("hot point").

Again, X-ray powder diffraction analysis was used to identify the softer material as a member of the chlorite mineral group. Chlorite minerals are made up of silicate and metal hydroxide layers that are stacked in

Figure 5. The green emerald cut in the earring on the right was identified as a natural emerald, while the emerald cut on the left was found to be a triplet consisting of a rock crystal quartz crown joined by green cement to a pavilion fashioned from an undetermined material.

various ways. In many, they are orderly; in some, there is no long-term order in the stacking arrangements. The latter was the case for this material. Because energy-dispersive X-ray fluorescence (EDXRF) analysis showed that the rock contained considerable magnesium, we suspect that the softer interstitial mineral is clinochlore, which is consistent with the X-ray powder diffraction pattern of a chlorite mineral.

MLJ

JADEITE JADE

With Copper Inclusions

In the Summer 1994 Lab Notes section (pp. 117–118), we described metallic inclusions (probably pyrite and pyrrhotite) in an unusually translucent jadeite cabochon. Last spring, we saw metallic inclusions in jadeite that had a different appearance.

A necklace of 72 translucent-to-opaque, mottled green-and-white beads was submitted to the West Coast lab for identification. To the best of our client's knowledge, this material was some sort of Central American jade. Tests on one bead revealed the following gemological properties: R.I.—1.66 (spot); an aggregate structure; inert to long- and short-wave UV; and a typical natural-color jadeite spectrum seen with the handheld spectroscope (437 nm line plus three "chromium" lines, at 630, 655, and 690 nm).

To further characterize this material, we ran an X-ray powder diffraction pattern. This matched that of our standard jadeite reference pattern. Furthermore, we did not see any polymer peaks with Fourier-transform infrared (FTIR) spectroscopy.

Figure 8 shows the most interesting feature of this material: bright brownish orange metallic flakes visible with magnification in some of the beads. X-ray powder diffraction confirmed that these flakes were elemental copper. We also saw a dark green fibrous mineral (figure 9), possibly an amphibole, in some beads. Amphiboles (e.g., glaucophane, actinolite) are typically associated with jadeite in high-pressure, low-temperature rocks (see, e.g., the jadeite chapter in W. A. Deer et al., *Rock-Forming Minerals: Volume 2A, Single-Chain Silicates*, John Wiley and Sons, New York, 1978), and pyrite-rich jadeite has been described from Guatemala (e.g., D. Hargett, "Jadeite from Guatemala: A Contemporary View," *Gems & Gemology*, Summer 1990, pp. 134–141). However, we have been unable to find any previous mention of copper as an inclusion in jadeite.

MLJ

Figure 6. Magnification clearly reveals the separation plane at the girdle of the earring-set assembled stone shown on the left in figure 5. The green band in the pavilion is a reflection of the green cement at the girdle. Magnified 12×.

With "Reconstructed" Area

Periodically, laboratory examination of an item submitted for identification reveals areas that were damaged and then subsequently repaired. In most instances, a portion of a gemstone has been broken off and then reattached with cement (as illustrated by the repaired chalcedony cameo described in the Fall 1982 Lab Notes, p. 169); in some cases, it is repaired with a different material (see Fall 1992 Lab Notes, pp. 193–194). We have also seen mineral specimens with crystals that had been broken and then reassembled. One of the more unusual repaired gems was a baroque pearl with a hole that was plugged with a small natural pearl (Summer 1990 Lab Notes, pp. 155–156).

Figure 7. The uneven surface of this polished cabochon of grossular garnet-rich rock resembles the surface of some pieces of jadeite jade that have been etched and polymer-impregnated. However, the undercut area in this case is a chlorite-group mineral, probably clinochlore. Magnified 16×.

Figure 8. These metallic brownish orange flakes were seen in a bead of jadeite jade that was reportedly from Central America. They proved to be copper. Magnified 15×.

Figure 9. A dark green fibrous mineral, possibly an amphibole, was seen included in this jadeite bead from the same necklace as the bead in figure 8. Magnified 15×.

Last summer, the West Coast lab was asked to identify a pierced carving made from a translucent material that was mottled white, green, and yellowish brown (figure 10). Standard gemological testing—including a spot R.I. of 1.66 and a 437 nm absorption line—showed that the carving consisted of jadeite jade. Other features seen in its spectrum (fine "chromium" lines in the red) proved that the green color was natural. During our examination with a binocular microscope, we noted that an area on the top had been repaired. However, not only had a broken piece of the original carving been reattached, but a translucent material—probably a polymer-like substance—was also used to fashion a replacement for the rest of the broken portion (figure 11). We hypothesized that the damaged surface was first "built up" with some form of cement or plastic, and then fashioned to imitate the missing part.

On the basis of this examination, we identified the carving as jadeite jade, with the green areas being of natural color. A note to the report's conclusion stated that the carving had been repaired and mentioned that there was evidence of luster enhancement (also discovered during the examination and probably paraffin, which is commonly used for that purpose). *RCK and SFM*

PEARLS

Abalone

In the past, both the West and East Coast labs have seen several natural abalone pearls shaped like sharks' teeth. When one particularly fine example arrived at the West Coast lab for identification recently, we decided to report on this recurring phenomenon.

This roughly triangular pearl (39.40 mm long × 26.78 mm wide × 12.00 mm thick) displayed a striking combination of body color and orient (iridescence) in green, blue, and purple hues (figure 12). Similar types of pearls frequently have a concave base bordered by a dark horny seam, and are well illustrated in the literature (e.g., Shohei Shirai, *Pearls and Pearl Oysters of the World*, Marine Planning Company, Okinawa, Japan, 1994, p. 92). An X-radiograph (figure 13) revealed the characteristic large hollow center, with roughly the same outline as the pearl, surrounded by several layers of nacre (which is less transparent to X-rays).

Abalone pearls are rarely spherical. The various shapes and colors depend on where they grow in the univalve mollusk. Tooth-shaped pearls grow next to the shell in the horn-like gonad of the abalone (P. V. Fankboner, "Abalone Pearls: Natural and Cultured," *Canadian Gemmologist*, Vol. 16, No. 1, 1995, p. 4).

The growing popularity of the abalone pearl's magnificent iridescent hues has led to the appearance of several abalone pearl–culturing farms along the American West Coast, from Canada to southern California, as well as in several other locations outside North America (see, for example, the "Cultured Abalone Pearls" entry in the Gem News section of this issue). *CYW*

Partially Coated to Conceal Old Drill Holes

Although natural pearls are rarely subjected to other than traditional processing, we have seen some notable exceptions. Among these are the pearls contained in four strands examined by the West Coast lab in 1995. Many of these pearls had been partially coated to conceal old drill holes. The location and shape of these drill holes (near the perimeter, not through the center, of the pearl) indicated that they were probably once used to attach the pearls to fabric. After the old holes were filled, the pearls were redrilled through the center for stringing on a necklace.

Under normal viewing conditions, the old drill holes were cleverly disguised by the soft coating, which had a "pearly" luster and closely

Figure 10. An area on the top of this (10.41 cm high) jadeite carving has been repaired with what appears to be a polymer-like substance.

matched the off-white color of the pearls (figure 14). These drill holes were so well camouflaged that they could have been easily missed had the pearls not been X-rayed or closely examined with magnification.

To determine the composition of the coating, we subjected it to X-ray powder diffraction analysis. However, the results were too vague for conclusive identification. *CYW*

PERICLASE, Possible Confusion with Grossular Garnet

A 5.49 ct transparent near-colorless emerald cut prompted several questions at the West Coast lab last summer. Gemological properties were: R.I.—1.738; S.G.—3.59; optic character—singly refractive (with slight anomalous double refraction, seen as first-order gray strain colors in the polarized light); no fluorescence to

Figure 11. Magnification revealed not only that a piece at the top of the jadeite carving shown in figure 10 had been glued back on, but also that an adjacent area had been "reconstructed" with a polymer-like substance. Magnified 10×.

long-wave, but weak yellow to short-wave, UV radiation; and no absorption features seen with the handheld spectroscope. With magnification, we noted a slight cloudiness throughout the stone, which showed graining in a cubic growth pattern when viewed through the pavilion. The surface of the stone had a poor polish, with pitting visible at higher magnification.

One gem material that has these properties is near-colorless grossular garnet, which is known to occur, for instance, in East Africa and in Asbestos, Quebec, Canada. For direct comparison with the unknown material, we examined four colorless grossulars from these two localities. The gemological properties of the unknown stone were not significantly different from the ranges of these garnets: R.I.—1.736–1.738; S.G.—3.59–3.66; optic character—singly refractive, with slight anomalous double refraction; and no distinct absorption features seen with the handheld spectroscope. With magnification, we saw crystalline inclusions in two of the grossulars, but two were "clean." One slight difference we noted between the comparison garnets and the unknown sample was that the grossular comparison stones showed faint orange fluorescence to long-wave UV radiation and

Figure 12. Abalone pearls are noted for their striking iridescence. This 45.53 ct (182.12 grains) shark-tooth-shaped abalone pearl is typical of many that have been seen in the lab.

Figure 13. An X-radiograph of the pearl seen in figure 12 reveals the large hollow center characteristic of natural abalone pearls, surrounded by several layers of nacre, which is less transparent to X-rays.

weak orangy yellow fluorescence (or were inert) to short-wave UV.

However, one staff member sensed that the inclusions and surface polish of the unknown did not "seem right" for grossular garnet. This was confirmed by EDXRF spectrometry (which revealed a high Mg content, less Fe, and possible traces of Ca, Cr, Mn, and Ni) and an X-ray powder diffraction pattern which matched that of periclase (MgO). We could not, though, establish definitively whether the specimen was natural or synthetic. The trace-element contents do not necessarily imply natural origin, since the source material for synthetic periclase is natural magnesite (see G. Brown, "Australian Synthetic Periclase," *Australian Gemmologist*, November 1993, pp. 265–269), which has these same trace elements. In addition, although natural periclase usually occurs in small gray nodules, we could not discount the possibility that fine crystals had been found and not yet reported.

In his description of facetable near-colorless synthetic periclase (see article cited above), G. Brown noted that much periclase tends to react with the atmosphere to form a surface coating of brucite, $Mg(OH)_2$, or similar phases. This probably accounted for the pitted surface in the sample we examined. A freshly polished periclase might be easily confused with (near-colorless) grossular garnet, since the properties are so close and can overlap. A cause for still greater concern is the green synthetic periclase (colored by chromium) described by H. Bank ("Grüner schleifwürdiger synthetischer Periklas," *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, Vol. 29, No. 1/2, pp. 88–89), which could be confused with green garnets.

MLJ, SFM, and Dino DeGhionno

Imitation RUBY

Dyed Quartz

A necklace that superficially appeared to be composed of ruby beads (figure 15) was submitted to the East Coast laboratory for identification. Exposure of the beads to long-wave UV radiation revealed the unnatural orangy red color of a fluorescent dye (figure 16). With that observation and routine gemological testing, which revealed a 1.54 R.I., it was easy to determine that we were dealing with dyed, quench-crackled quartz.

GRC

Ruby/Ruby Doublet

We seldom see doublets consisting of two sections of natural ruby (called "genuine" or "true" doublets by various authors). One such ruby/ruby doublet was reported in the Spring 1987 Lab Notes section (pp. 47–48). Only now, more than eight years later, has the East Coast lab received another such stone. Routine gemological testing established that both parts were indeed natural ruby.

Because the separation plane (figure 17) was below the girdle, the fact that the stone was assembled could be easily disguised when it was mounted, particularly if it was bezel set. This stone weighed precisely 1.00 ct, which illustrates a point made in the 1987 lab note: If the deception is successful, the perpetrator stands to profit handsomely, since natural rubies of one carat or more bring a premium price.

GRC and TM

Figure 14. To help conceal an old drill hole, this pearl was partially coated with an off-white material that has a "pearly" luster. Magnified 16×.

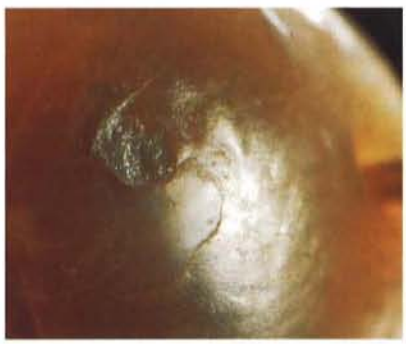


Figure 15. The dyed quench-crackled quartz beads in this necklace (graduated from approximately 22.5 × 15 mm to 10 × 6 mm) superficially resemble ruby.

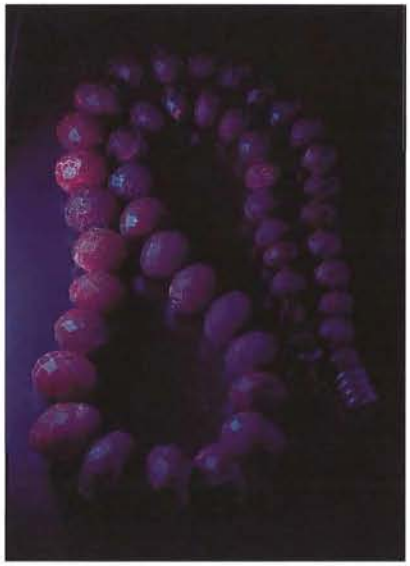


Figure 16. The dye in the beads shown in figure 15 fluoresced readily to long-wave UV radiation.

SYNTHETIC RUBY,
With Fanciful Polishing Marks

In September 1995, an easily identified material nevertheless provided the West Coast Gem Trade Laboratory with a certain amount of quiet satisfaction, and a small difference in artistic opinion. The material was purplish red, 5.30 ct, and revealed obvious internal clouds (most likely decorated dislocations, but possibly fine gas bubbles) and gemological properties consistent with ruby. The table facet showed the crescent-shaped crazing that is frequently referred to as rapid-polishing marks.

In their book *Gemology* (2nd ed., Wiley Interscience, New York), authors C. S. Hurlbut and R. C. Kammerling noted that similar surface features are occasionally seen in old flame-fusion synthetics, the result of heat from polishing too rapidly. However, such marks are sometimes seen on natural rubies and sapphires as well. In the case of this piece, curved striae as well as the internal clouds proved it to be synthetic. Very likely it was an older Verneuil product, since modern polishing methods almost entirely eliminate such marks.

The satisfaction, and the slight difference in opinion, resulted from viewing the table in two different orientations. One laboratory denizen immediately stated that her view through the microscope resembled a landscape painted in the manner of Chinese watercolors: The rapid-polishing marks looked like mountain tops, and the internal clouds resembled fog (figure 18). However, another resident gemologist, looking at the stone after it had been rotated 180°, but with the table in the same plane, thought that the marks resembled a flock of birds in a cloudy sunset.

MLJ and RCK

Figure 17. This profile view shows the separation plane of a ruby/ruby doublet. Immersion, magnified 17×.

SAPPHIRE,
With Rounded Facet Junctions

There are instances where the condition of a gem's facet junctions can provide useful information during examination with magnification. Examples include the abraded facet junctions on some zircons and sapphires (both considered to be the result of increased brittleness caused by heat treatment), the dark color outlining facet junctions on diffusion-treated corundums (seen with diffuse illumination) and the exceptionally sharp facet junctions of diamond (which are helpful in distinguishing diamond from its softer imitations—such as CZ). Rounded facet junctions are also seen on glass and plastic imitations of gems that have been "fashioned" by molding rather than cutting on a lap. Occasionally, we see this feature on natural gems, usually on stones of fairly low hardness that appear to have been polished by inappropriate techniques (e.g., too much pressure was applied while the stone was being pol-

Figure 18. The rapid-polishing marks and included clouds resemble a landscape of mountains and fog in this view of a 5.30 ct synthetic ruby. Viewed in another orientation (turn the page upside down), these features resemble a flock of birds at sunset. Magnified 10×.

ished on a fairly soft, flexible lap). This has also been noted on stones of moderate hardness, such as the tanzanite reported on page 176 of the Fall 1983 Lab Notes section.

In late spring 1995, the GIA Gem Trade Laboratory's West Coast facility was asked to identify a 0.71 ct transparent purplish pink oval modified brilliant. Traditional gem testing methods identified the stone as a pink sapphire. Although the inclusions—fine, short needles and transparent, birefringent crystals—were ambiguous, trace-element analysis showed that the stone was natural. What struck us as highly unusual during the microscopic examination was the condition of the facet junctions, which were very rounded (figure 19). As noted in the above-referenced entry, this may have resulted from an inappropriate polishing method (such as polishing with diamond grit on a soft lap), or it could have occurred if the stone was repolished with a buff normally used for polishing cabochons rather than a faceting lap. *RCK*

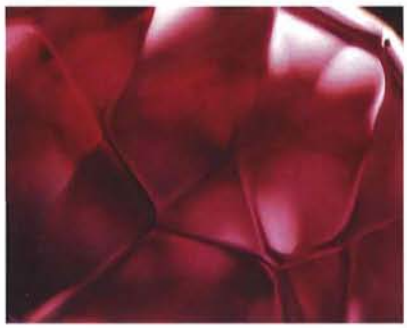


Figure 19. It is very unusual to see rounded facet junctions—like those evident on this 0.71 ct purplish pink natural sapphire—on corundum gems. Magnified 40×.

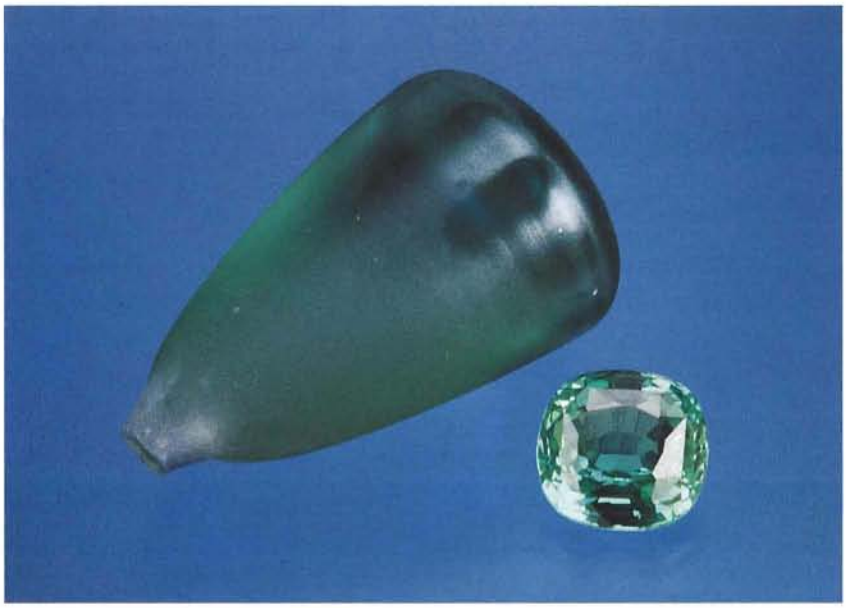


Figure 20. The origin of this 5.90 ct synthetic sapphire, shown here with a 116.71 ct boule of green synthetic sapphire, was determined on the basis of its absorption spectrum and inclusions.

Green SYNTHETIC SAPPHIRE

In the Spring 1995 Lab Notes section (pp. 57–58), we described a green synthetic star sapphire that was examined in the West Coast lab. As noted in that entry, green star sapphires—natural or synthetic—are not commonly encountered in the gem trade. However, another green gem (not asteriated) with the properties of corundum was received for examination in the West Coast lab late last summer.

This 5.90 ct transparent green cushion mixed cut (figure 20) had R.I. values of 1.762–1.770, a birefringence of 0.008, and an S.G. (determined hydrostatically) of 4.00; a uniaxial interference figure was noted between crossed polarizers; and the item was inert to both long- and short-wave UV radiation. All of these properties are consistent with a sapphire, either natural or synthetic. However, with a desk-model spectroscope we noted the following: a cutoff at about 410 nm, weaker general absorption from 440 to 470 nm, and a diffused band at about 640–680 nm. This last feature is similar to, but broader than, the one absorption feature we noted in the synthetic star sapphire mentioned above, and the diffused band in the 400 nm range is quite different from the "iron series" in the 450–470 nm range typical of natural green sapphires. Examination with magnification revealed curved color zones that contained clouds of gas bubbles, confirming that this was a synthetic. The curved growth was most clearly resolved when the gem was examined while it was immersed in methylene iodide.

EDXRF analysis revealed only aluminum, an essential component of corundum (Al_2O_3), and cobalt. As with the previously examined green synthetic star sapphire and with commercially available nonphenomenal green synthetic sapphires manufactured in Switzerland, we believe that Co^{3+} is the sole cause of color in this specimen. *RCK*

PHOTO CREDITS

Nicholas DelRe supplied the pictures used in figures 1–4 and 15–17. Shane McClure provided figures 5–7, 10-12, 14, and 19. The photomicrographs in figures 8, 9, and 18 were taken by John I. Koivula. Maha DeMaggio provided figure 20. The X-radiograph in figure 13 is by Cheryl Y. Wentzell.

GEM N·E·W·S

TUCSON '96

The annual February series of shows held in Tucson, Arizona, has become such an industry institution that it almost requires no introduction. The many Tucson exhibitors represent four distinct approaches to natural products, from unprocessed minerals through finished jewelry: fashioned stones (including diamonds and colored stones of every description) and ornamental materials; findings and jewelry supplies (including beads); finished pieces (mostly jewelry, but also carvings and other *objets d'art*); and items for collectors (such as mineral and fossil specimens). This year, the editors and contributing editors were helped by many people. Special thanks go to GIA's Bill Boyajian, Brook Ellis, Debbie Hiss-Odell, D. Vincent Manson, Andrea McShane, and James E. Shigley, as well as *G&G*'s technical editor Carol Stockton and GIA Gem Trade Laboratory's Nick DelRe and Cheryl Wentzell.

DIAMONDS

Matrix diamond specimens from China and Russia. D. J. Parsons, Rapid City, South Dakota, had three approximately 2 cm samples of eye-visible diamonds in matrix from Mengyin, Shandong Province, China. Several dealers had Russian diamond-in-matrix specimens, some with exact localities such as the Udachnaya kimberlite pipe.

Synthetic diamonds are in the marketplace. The Morion Company, Brighton, Massachusetts, had synthetic diamond crystals on display and for sale. One of the editors (MLJ) looked at three crystals at their booth: The crystals were yellow octahedra with one truncated pyramidal corner. Gray to somewhat blue color zoning was eye-visible in the center of each crystal. A Morion representative reported that these crystals are produced in a factory outside of Moscow, at a rate of 15–20 carats per month. Prices ranged from $265 per carat (for half-carat crystals) to $1,750 per carat for 2.29 ct crystals, according to a price list Morion handed out at the show.

Another firm, Pinky Trading of Los Angeles, California, also had about 10 faceted Russian synthetic diamonds for sale at Tucson. These samples appeared to be similar to the synthetic diamonds manufactured in Novosibirsk and reported on by Shigley et al. (*Gems & Gemology*, Winter 1993, pp. 228–248).

Synthetic moissanite as a diamond simulant. A "new" diamond simulant debuted at Tucson this year: Although not a new material, synthetic moissanite previously had not been actively marketed as a diamond substitute. Synthetic moissanite (silicon carbide, SiC) is probably more commonly known in its polycrystalline form—carborundum—which is used as an abrasive.

Over the years, the GIA Gem Trade Laboratory has examined several faceted examples of synthetic moissanite that were submitted for identification. These samples—all of which were green—were visually convincing as diamond simulants. Now, a company called C3 Diamante of Raleigh, North Carolina, is preparing to market synthetic moissanite, not only the typical dark green color, but also pale green to pale brown. Although synthetic moissanite in these latter colors had been reported before, previous efforts to control the color (or even the growth) of facetable single crystals were unsuccessful (see, for instance, Kurt Nassau, *Gems Made by Man*, Chilton Book Co., Radnor, Pennsylvania, 1980). Representatives of C3 Diamante believe that they have overcome at least some of these problems and will be able to market this material later this year.

We were not able to acquire any samples for testing purposes by press time. The more than a dozen faceted samples we saw at the show were for display only. However, we did briefly examine one faceted synthetic moissanite with a microscope. Although uniaxial, the stone was cut with the optic axis perpendicular to the table facet, so no doubling of back facets was observed when the sample was viewed table up. When we exam-

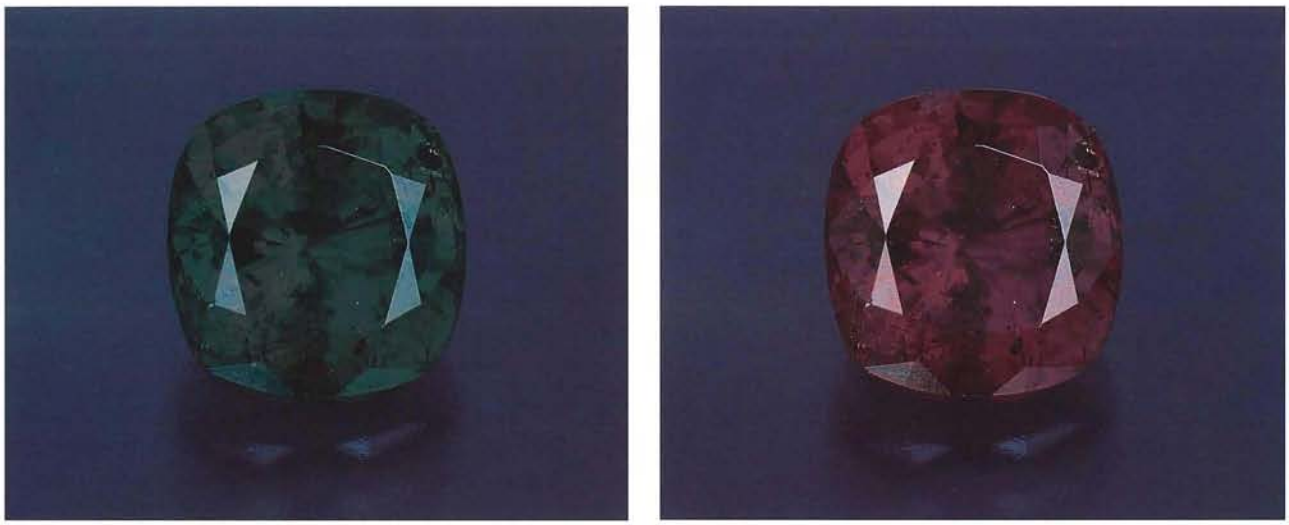


Figure 1. In fluorescent light (left), this 3.29 ct color-change pyrope-spessartine has the bluest color that we have yet seen in a garnet; it is shown in incandescent light on the right. Photos by Shane F. McClure.

ined the stone through the girdle, doubling of the most distant facets was seen. We will examine and report on this material in more depth when samples become available.

Published properties for synthetic moissanite (Joel Arem, *Encyclopedia of Gemstones*, 2nd ed., Van Nostrand Reinhold, New York, 1987) are: crystal symmetry—hexagonal, rarely cubic; refractive indices of $n_o = 2.65$, $n_\varepsilon = 2.69$; hardness—9½; birefringence—0.043; dispersion—about 0.09; specific gravity—3.17 to 3.20; cleavage—none.

COLORED STONES AND ORGANIC MATERIALS

Color-change garnet. The Fall 1988 issue of *Gems & Gemology* (pp. 176–177) reported on four exceptional garnets from East Africa with a color change that approached that of fine Russian alexandrite. Color-change garnets of that quality have continued to be extremely rare. This year in Tucson the editors saw one such garnet (figure 1) at the booth of K & K International of Falls Church, Virginia.

Gemological testing of this 3.29 ct stone showed properties consistent with those reported in 1988: a refractive index of 1.770 and an absorption spectrum (as seen in a Beck desk-model prism spectroscope) typical for color-change pyrope-spessartine garnets (see "A Proposed New Classification for Gem Quality Garnets," by C. M. Stockton and D. V. Manson, *Gems & Gemology*, Winter 1985, pp. 205–218). Energy dispersive X-ray fluorescence (EDXRF) analysis showed relatively high amounts of manganese and vanadium, and a comparatively small amount of chromium; these findings were also consistent with the stones previously examined.

One important feature of this particular garnet did separate it from the ones reported earlier—its color, which changes from reddish purple (in incandescent light) to bluish green (in day or fluorescent light). For many years, gemologists have searched for a truly blue garnet; still, blue is the only color in which garnets have not been found. We do (rarely) see color-change garnets that have a blue hue in day or fluorescent light, but—to date—the blue has always been a secondary color, that is, modifying the predominantly green hue. The daylight color of this stone has more blue than we have yet seen in a garnet, using a standard gemological illuminant.

A caution concerning this stone is warranted, especially since we have already seen others like it. The color change of this garnet is so much like that of a fine alexandrite that visually they are virtually indistinguishable. Of course, a simple test for double refraction or pleochroism would show that it is not an alexandrite, but we have seen garnets similar to this one traded as alexandrites in the past. As always, gemologists should remember never to rely on visual appearance—or any single test—to identify a stone. Identifying this stone as an alexandrite would be a costly mistake indeed.

Heliodor from Tajikistan. Previous Gem News entries have reported on purple scapolite (Fall 1995, pp. 211–212) and red spinel (Fall 1995, p. 212) from Tajikistan. New at Tucson this year was yellow beryl—heliodor—from this nation. Mark Herschede, of Turmali & Herschede, Sanibel, Florida, loaned the editors five faceted examples and nine rough crystals for examination (see, e.g., figure 2).

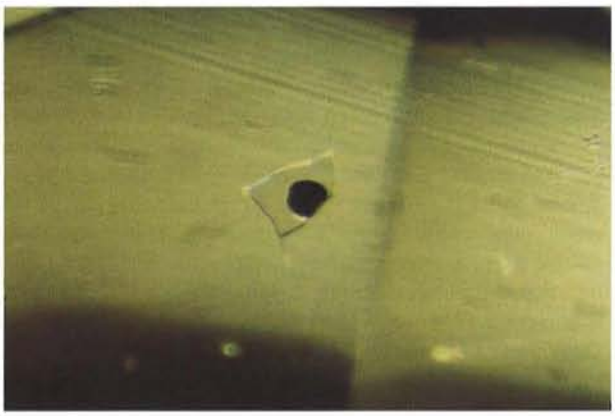
The faceted stones ranged from 6.80 to 14.39 ct. All were yellow, with even color distribution and very weak pleochroism in yellow to slightly darker yellow. The stones were uniaxial negative (R.I.'s of 1.571–1.575 [n_ε] and 1.578–1.581 [n_o]) with birefringences of 0.006–0.007. S.G.'s ranged from 2.69 to 2.72; the stone with the highest refractive indices also had the highest S.G. We did not see any spectra with the handheld spectroscope; nor did any of the stones react to the (Chelsea) color filter. All were inert to long-wave UV radiation; one stone fluoresced a faint, even greenish yellow to short-wave UV, but the others were inert. Among the inclusions were fine, wispy or small, liquid fingerprints; needles (for the most part running the length of the stone, with some in random orientation), straight and angular internal growth zoning, and pinpoints. Two-phase inclusions (figure 3)

Figure 2. These faceted stones and crystals of heliodor come from Tajikistan. The longest crystal is 50.75 mm (49.92 ct); the three faceted stones weigh (from left to right) 8.10, 11.76, and 10.03 ct. The cut stones were fashioned by David Brackna, of Germantown, Maryland. Photo by Maha DeMaggio.

were seen in two of the stones. EDXRF spectroscopy revealed Al, Si, Mn, Fe, Zn, Ga, Cs, and Rb.

The nine rough crystals weighed 9.70–49.92 ct; the largest measured 50.75 × 11.45 × 9.07 mm. These were singly or doubly terminated hexagonal prisms; each of the doubly terminated crystals had at least one severely etched termination. Faces observed were tentatively identified as prisms $\{10\bar{1}0\}$ and $\{21\bar{3}0\}$; pinacoid $\{0001\}$; and pyramids $\{10\bar{1}1\}$ and $\{11\bar{2}1\}$; overall, the crystals resembled examples from Mursinka, Ural Mountains, Russia, as illustrated in Goldschmidt's *Atlas der Kristallformen* (originally published in 1913; reprinted by Rochester Mineral Symposium, Rochester, NY, 1986). In some cases, the prism faces were also etched (figure 4), and some crystals showed conchoidal fracture surfaces. A white micaceous material was visible in etch pits on two samples, and one crystal contained a 3.5-mm-long dark greenish brown crystal with the morphology of tourmaline.

Figure 3. A two-phase (liquid and gas) inclusion is evident in this 6.80 ct faceted heliodor from Tajikistan. Length of inclusion, about 0.25 mm; photomicrograph by John I. Koivula.



Mr. Herschede and Rob Lavinsky (The Arkenstone, San Diego, California), who distributes mineral specimens from this region, provided some locality and production information. The heliodor mine, called *Zelatoya Vada* (approximate translation, "yellow water") by its owners, is located near Lake Rangkul, east of the town of Murgab. Each pocket in this pegmatite produces a slightly different set of associated minerals. The matrix material is the clevelandite variety of albitic feldspar, and is similar to that from deposits in Pakistan. Other associated minerals include: white and purple apatite, schorl, topaz, red-to-orange spessartine, quartz, and minerals tentatively identified as loellingite and stibiotantalite.

Figure 4. Deep surface etching is evident on the prism face of a 9.74 ct heliodor crystal from Tajikistan. Field of view, about 5.5 mm; photomicrograph by John I. Koivula.

The Zelatoya Vada deposit was discovered in 1991; the first pocket produced a "minimal" amount of facet-grade rough and matrix mineral specimens. The pegmatite itself may be 3 to 5 km long; by the time of the Tucson shows, pockets first uncovered in 1994 had produced about 30–40 kg of material. Mr. Herschede believes that his source will produce 4–10 kg per month as the operation grows. All mining is now done with hand tools and manual labor, and there are no plans to mechanize mining at such a remote and poorly accessible location.

"Leopard opal" from Mexico. Although the editors saw few genuinely new gem materials at Tucson this year, they discovered one while exploring the many gem-and-mineral-laden rooms at the Executive Inn: a black-and-white opal-bearing rock that has been tentatively named "leopard opal" by its distributor, gemologist-geologist Warren F. Boyd, of R. T. Boyd Ltd., Ontario, Canada. In its

best quality, "leopard opal" is a black vesicular basalt in which the vesicles are filled with white opal that shows green, red, blue, and yellow play-of color; when viewed as a whole, the stone appears to have black-and-white spots (hence the trade name), with flashes of color that quickly change as the stone or the light source is moved.

We obtained a 4.87 ct cabochon (figure 5) and a rough sample for gemological documentation. A spot R.I. of 1.46, typical for opal, was the only reading that could be determined. Because the material can be somewhat porous, we did not attempt to test for specific gravity. The opal portions fluoresce bluish white, with a stronger reaction to long-wave than to short-wave UV.

The material was found in the state of Hidalgo, in southern Mexico, according to Mr. Boyd. He could not give a more specific locality because the property is in the early stages of development. He did say, however, that reserves look very promising. One special feature of this material is that it can be cut in any size without having to make allowances for distribution of color or patches of matrix, as is the case for solid opal. "Leopard opal" can be used for beads and carvings as well as calibre-cut cabochons and other fashioned stones.

An impressive 2 kg boulder of the basaltic rough was being used to prop open the door to Mr. Boyd's room in the Executive Inn. However, because the discovery is so new, only a few cabochons were available. If the mining operation goes well, and if the size of the "door stop" is any indication, perhaps next year we will see a significant amount of "leopard opal" in Tucson.

Cultured abalone pearls. Cultured abalone pearls, long rumored to be in production, have finally reached the market. (For a brief discussion of natural abalone pearls, see the Lab Notes section of this issue.) According to research by biologist P. V. Fankboner, of Simon Fraser University, Burnaby, British Columbia (Canada), the American red abalone (*Haliotis rufescens*) is the largest

Figure 5. This 16-mm-long (4.87 ct) cabochon of "leopard opal" is from the state of Hidalgo, Mexico. Stone courtesy of Warren F. Boyd; photo by Maha DeMaggio.

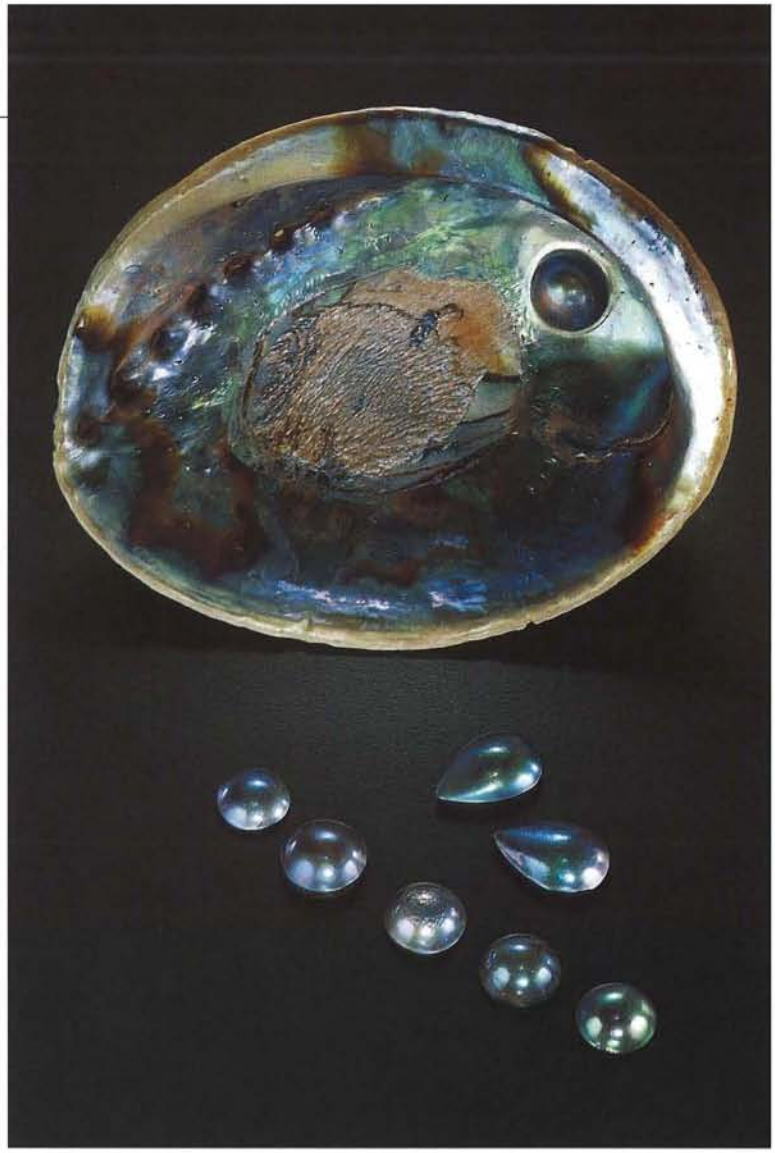


Figure 6. These abalone blister pearls (the buttons are about 2 cm in diameter) are from a culturing operation in New Zealand that uses paua abalone shells like the one shown here. Photo by Robert Weldon.

and most prolific producer of gem-quality cultured abalone pearls. However, cultured abalone pearls are being produced elsewhere as well; one of the newest localities is New Zealand. Liz and Michael McKenzie, directors of Empress Pearl of Christchurch, New Zealand, were at Tucson this year with their first production of cultured blister pearls from the paua abalone (*Haliotis iris*), which is being promoted by the McKenzies as the Empress abalone. Although the McKenzies did not have a booth, they did have several trays of cultured abalone blister pearls. These samples were mostly large (about 2 cm), round, high-luster blister pearls that had been fashioned into mabe-type pieces with a polished paua shell backing (figure 6; for more information on this type of cultured blister pearl, see the entry on an "Abalone 'Mabe' Pearl" in the Winter 1994 Lab Notes section, p. 268). Since the paua abalone produces the most iridescent nacre of all abalone, its pearls boast the most colorful orient. The hues range from shades of blue and green—normally associated with nat-

Figure 7. This 29.71 ct cushion-cut spessartine ("Mandarin" garnet) is from the vicinity of the Marienfluss River, Namibia. The matrix piece behind it (about 7 cm high) shows how the garnets are found in black, manganese-rich veins. Courtesy of Colgem Ltd.; photo by Robert Weldon.

ural abalone pearls—to a distinct purple that, in our experience, is very unusual. The McKenzies said the purple was their rarest color.

One major difficulty in culturing abalone pearls has been the implantation of nuclei. Free-forming (nonblister) pearls are difficult to cultivate because the bead is so easily rejected by the univalve abalone, which can use its large foot to eject the implanted nucleus. Formerly, the greatest success in culturing blister pearls in this mollusk was achieved by attaching the bead nucleus firmly to the shell beneath the mantle tissue. According to the McKenzies, Empress Pearl culturists currently use special tools to slide the plastic nucleus behind the mantle of the abalone and insert it into the cavity in the "horn" of the shell, from which the abalone has difficulty ejecting it. This process must be done with great care, as abalones are "hemophiliacs" and will likely die if wounded. The blister pearls take about 30 months to grow, at which time they are cut from the shell, filled with a polymer, and backed with abalone shell. The abalones can only be used for pearl culturing once, after which the meat is sold to restaurants and stores.

An article on this subject is intended for a future issue of *Gems & Gemology*.

Update on Namibian spessartine. Namibian spessartine—sometimes called "Hollandine" or "Mandarin" garnet—has been described in earlier Gem News sections, including Spring 1993 (pp. 61–62), Winter 1993 (p. 293), and Summer 1995 (p. 134). This material was conspicuous at the Tucson shows this year, especially a noteworthy 29.71 ct stone and some matrix specimens (figure 7).

The Summer 1995 Gem News section described the chemistry of these garnets. Contributing Editor Henry A. Hänni, who provided the analyses for that report, has sent additional information. At this time, two companies are working at least two different mining sites in northwest Namibia. The SSEF Swiss Gemmological Institute received the first material they examined from Israel Eliezri, of Colgem Ltd., Ramat Gan, Israel, who is working with one of the mines in northwest Namibia. The mining area lies in metamorphic terrain in a remote region just east of the Skeleton Coast and south of the Kunene River (which forms the northern border with Angola), near the Marienfluss River. The parent rock consists of inclined mica schist strata in which the spessartines occur both as nodules and as beautifully developed idiomorphic crystals. At Tucson, Mr. Eliezri informed another editor (MLJ) that the garnets are found in the black streaks of higher manganese concentration that run through the host rock. Frequently, the garnets nucleate on individual particles of black manganese oxide.

In Winter 1993, SSEF received Namibian spessartines from another mine, worked by Alan Roup of G.E.M. Namibia Pty. Ltd., Jerusalem, Israel. This mine is 28 km south of the Kunene River contact with the Marienfluss, and 320 km by road northwest of the village of Opuwo. The mine is situated along a ridge that consists of mica schist—similar to the Colgem occurrence—which protrudes from the desert plain. Here the garnets also occur in (somewhat larger) nodules, but the nodules appear to have been fractured at some point in the past. Fibrous inclusions reduce the clarity in much of the most recently found material, although the garnets are comparable in color to those from the Colgem occurrence.

SSEF analyses of the spessartines from the Kunene occurrence revealed characteristics similar to those previously reported: R.I.—1.789–1.790; optic character—isotropic; S.G.—4.12 to 4.14; absorption spectrum (with a handheld spectroscope)—dominant lines at about 412, 424, 432 (edge), 462, and 485 nm (typical of spessartine) as well as a line at 495 nm. X-ray diffraction analysis gave a unit-cell edge length (lattice constant *a*) of 1160.2 picometers (11.60 Å).

The chemical compositions of seven samples, as measured by electron microprobe on at least two points

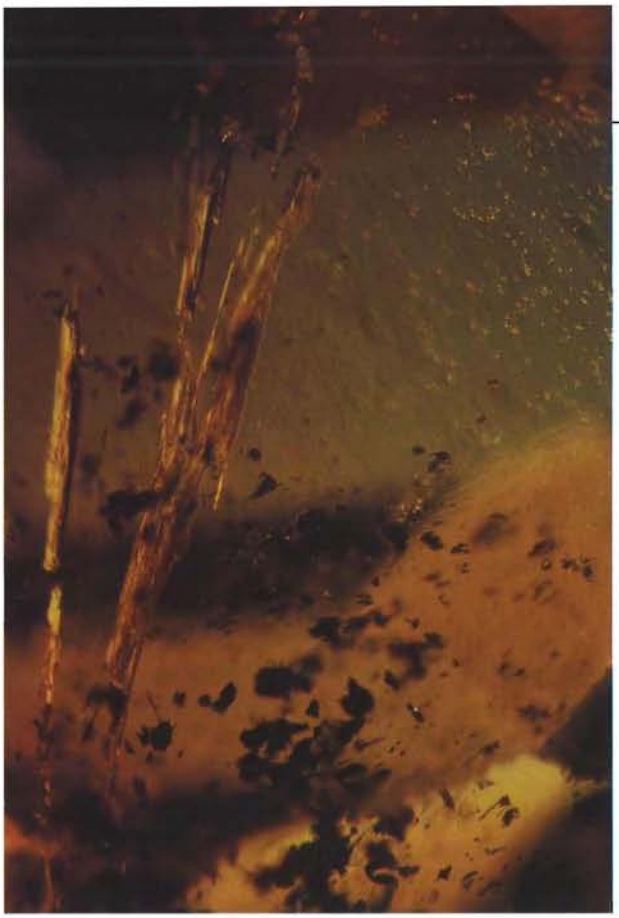


Figure 8. Among the features seen in spessartine from Kunene, another Namibian locality, are colorless fibers (tirodite) and black anhedral inclusions (iron and manganese oxides). Photo courtesy of SSEF; magnified 30×.

per stone, and normalized to garnet end-members, were in the following range: 12–15 mole percent (mol%) pyrope; 0.0–1.5 mol% almandine; 84–86 mol% spessartine; and 1.0–1.5 mol% grossular. We can understand the color of these garnets, given this chemistry. The Kunene material contains almost no almandine component, which adds a brown tint to the bright orange color when present. Any almandine component present would be very strongly colored, so that only concentrations less than 1 mol% do not appreciably influence the spessartine color. In addition, pure pyrope and grossular are colorless, so these components do not add color but dilute the intrinsic spessartine color.

Among the inclusions observed were colorless grains (found to be quartz), colorless fibers, and black anhedral shapes (figure 8). These inclusions were identified by SEM-EDS and microprobe. In the Summer 1995 Gem News section, the colorless fibers—birefringent acicular crystals—were tentatively identified as tremolite, undoubtedly because they resemble the tremolite inclusions in Sandawana emerald. Professor B. Lasnier, from Nantes (France), suggested that they might be tirodite (figure 9), a Mn-Mg-amphibole, which SSEF has confirmed by SEM-EDS and X-ray diffraction analysis. The black inclusions were ilmenite, hematite, and senaite, a Mn-Fe-Ti-Pb oxide that occurred as tiny black spots in some of the spessartines. One inclusion was identified as barite by means of the Raman microprobe.

The pure orange seen in most of the Namibian production is also encountered in some spessartines from California (the Little Three Mine) and Madagascar.

Large taaffeite crystal from Sri Lanka. U. A. Ranatunga, of Lanka Rare Gems Exporters and Lapidary, Ratnapura, Sri Lanka, showed one of the editors (MLJ) a light purplish pink rounded bipyramidal crystal with some iron staining on its surface. A gemological report that accompanied the crystal said that it was a 36.05 ct taaffeite, with refractive indices between 1.718 and 1.723; the report also contained a photograph that clearly matched the crystal.

Tanzanite beads. Among the more unusual items we saw this year were four single-strand necklaces of graduated, faceted tanzanite beads (much like the emerald beads mentioned in last year's Tucson report, Spring 1995, p. 61). Seen at the booth of the Black Star Trading Company of Flagstaff, Arizona, these strands were about 36 cm (14

Figure 9. In some broken pieces of Kunene spessartine, tirodite fibers were seen extending above the surface, here by about 7.5 mm. Photo courtesy of SSEF.

Figure 10. This 7.19 ct alexandrite (as it appears in fluorescent [left] and incandescent [right] illumination) is from the Tunduru region of Tanzania. Photos by Robert Weldon.

inches) long. The largest bead measured about 5.5 mm in diameter. Some variation in body color—from blue to violet—was noted among the beads, and many contained small black inclusions.

Gem materials from the new locality at Tunduru, Tanzania. Finds of gem materials in Tanzania were reported in the Spring 1995 (pp. 64–65) and Summer 1995 (pp. 133–134) Gem News sections. At Tucson this year, we saw a broad variety of gem materials from the region near the town of Tunduru, in the far south of Tanzania. Many dealers have likened the wealth of gem species in the area to that of Sri Lanka. Steve Ulatowski of New Era Gems, Grass Valley, California, said that among the gem materials from Tunduru are: ruby; blue, pink, and other colored sapphires; spinel; chrysoberyls, including an unusual "mint" green (vanadium) variety, as well as alexandrites and cat's-eyes; garnets, including chrome pyrope, rhodolite, color-change, and light pink garnets; tourmaline; topaz; amethyst; tsavorite; zircon; and even some diamonds. Horst Krupp, of La Costa, California, confirmed this list and added that aquamarine—as well as green, white, and yellow beryls—have also been found in this area along arteries of the Ruvuma River. (He also noted that gem materials are being recovered across the border, in Mozambique.) Especially notable at Tucson was a 7.19 ct alexandrite from Tunduru (figure 10), shown by Michael Couch and Associates of Cumming, Iowa.

Unwilling or unable to specify exact amounts, producers would only say that quite a lot of material had been removed from Tunduru. Many reported a vast gem field (Dr. Krupp estimated that the gem-bearing area exceeded 500 km^2 [about 200 square miles]) that appears to hold large reserves (figure 11). Most of the mining, which is almost entirely alluvial, was proceeding with the use of very simple techniques, but some miners had pumps. One of the more sophisticated operations (figure 12) used a motorized dredge to mine around rocks in deep areas of the river.

In mid-January, all mining permits held by foreign nationals in were suddenly revoked. New regulations, as of March 1, prohibit mechanized mining in Tunduru and restrict claims to Tanzanian nationals, according to Abe Suleiman in the April 1996 *ICA Gazette*. To further pro-

Figure 11. This aerial photo of the Muhuwesi River, part of the Tunduru gem field (taken in December 1995), shows the main gem-mining camp left of the bridge and, on the far right, the dredging area for this operation (which is about 3 km away). Photo courtesy of Randy Wiese, Michael Couch and Associates.

tect small-scale mining and develop a cutting industry in Tanzania, foreign involvement is limited to joint ventures for the export of polished goods only.

**Editor's note: We believe that the material tentatively identified as being from Songea in the Summer 1995 Gem News entry was probably from Tunduru.*

ENHANCEMENTS

Update on polymer-impregnated malachite. The Fall 1995 Gem News section (p. 213) reported on fibrous malachite that was impregnated with Opticon resin. Joe Jelks has corrected some of the information provided in that entry. Specifically, Opticon hardener *is* used at one stage of the impregnation process: Fibrous malachite (from Morenci, Arizona) is heated, filled with Opticon resin, heated again, slabbed, and heated once more, filled with Opticon resin, and heated yet again. Then, after the stones have been preformed, Opticon resin *with* hardener is brushed on them. Adding the hardener at this stage eliminates what would otherwise be a long wait between sanding steps in the final polishing of this material.

SYNTHETICS AND SIMULANTS

Beryl triplets imitating Paraíba tourmaline. The Winter 1995 Lab Notes section (pp. 272–273) reported on topaz triplets that resemble Paraíba tourmaline. Grimm Edelstein, of Idar-Oberstein, Germany, was marketing another Paraíba imitation—triplets that reportedly consist of top and bottom pieces of near-colorless beryl held together (and colored) by a layer of blue-green glue. These convincing pieces rapidly sold out.

Figure 12. Randy Wiese, left, works a dredge on the Muhuwesi River, near the town of Tunduru, in December 1995. Photo courtesy of Randy Wiese.

Figure 13. This 75 ct construct (about 48 × 15 × 15 mm) was made from five individually fashioned pieces of quartz. Photo by Robert Weldon.

Faceted quartz construct. A quartz construct, "Congrego 1," was one of the more unusual pieces seen at Tucson this year. Carved by Klaus Schäfer of Idar-Oberstein, Germany, the approximately 75 ct piece (figure 13) is actually a composite of five separate carvings cemented together with a UV-setting epoxy. Such a technique enables sharp re-entrant angles in the finished construct.

The construct was displayed at the booth of Bernhard Edelsteinschleiferei, also of Idar-Oberstein.

The Winter 1995 Gem News section included abstracts and field trip reports from the November 1995 International Gemmological Conference (IGC) meeting in Rayong, Thailand. This issue's Gem News presents more reports from this meeting.

DIAMONDS

Fingerprints of natural diamonds—observations with cathodoluminescence. In the laboratory at the Gemmological Association of All Japan in Tokyo, Junko Shida has conducted extensive research into distinctive growth patterns in a variety of commercially important gems, including natural and synthetic rubies, sapphires, and diamonds. Her IGC presentation concentrated on the distinct cathodoluminescence patterns shown by many natural diamonds.

Each stone has a unique pattern. Because no two are exactly alike, when such a pattern is present it serves as a distinctive fingerprint for its diamond. During her research, Ms. Shida also observed that the cutting orientation of the original rough crystal sometimes could be determined from the pattern observed in a fashioned diamond. In the cathodoluminescence image in figure 14, the triangular pattern shows that an octahedral face of the original crystal was almost parallel to the table, making this stone a "three-point" diamond. By contrast, the essentially square image in figure 15 shows that this stone is a "four-point diamond," with the orientation of the table parallel to a possible cube face in the original rough.

COLORED STONES AND ORGANIC MATERIALS

Mineral inclusions in quartz. Dr. Edward J. Gübelin of Lucerne, Switzerland, showed photomicrographs of interesting and colorful mineral inclusions in quartz, including bright blue-green dioptase crystals (figure 16). The inclusions discussed and shown in this talk all had been identified by a variety of techniques, including Raman microspectrophotometry and X-ray powder diffraction analysis.

When quartz crystallizes, associated minerals from the geologic environment may be incorporated within a developing crystal, he said. Since quartz occurs in such a wide range of geologic environments, and can be found as a major or minor component in many rock types, it is not surprising that many different mineral inclusions are found in quartz. Examination of these inclusions and their position in the host quartz can help determine mineral crystallization sequences. When sufficient inclusions are present, the growth and subsequent geologic history of a quartz crystal can be recorded.

Montana sapphires. Robert E. Kane, of Helena, Montana, briefly discussed the history of sapphire mining and current mining activities in Montana at Yogo Gulch, the Missouri River deposits, and Dry Cottonwood Creek. He also detailed the mining and processing of sapphires from the Rock Creek deposit (Gem Mountain), near Phillipsburg, Montana.

Sapphire-bearing gravels are mined using excavators and then are screened, washed, and sluiced to separate heavy concentrates (including sapphires and any gold) from the waste material. The remaining waste is returned to the mine site for reclamation. After the sapphire is hand-separated from any obvious nontransparent, nonsapphire material, the sapphire concentrate is put into methylene iodide to insure that all materials with specific gravities less than 3.32 (such as quartz) are removed. It is then cleaned in acid and put under fluorescent lamps, where any remaining garnets are removed by hand before heat treating.

Details of the heat-treatment process are regarded as proprietary. However, Mr. Kane did say that the sapphires are initially heated under oxidizing conditions, after which the fancy yellows, oranges, and pinks are ready for cutting. The blue and green stones (which constitute the majority of Rock Creek sapphires) are subsequently heated under reducing conditions.

Figure 14. Cathodoluminescence reveals that the table facet of this diamond was oriented almost parallel to an octahedral face on the original crystal. Photo by Junko Shida.

Figure 15. The square pattern revealed by cathodoluminescence means that the table facet of this diamond was oriented along a possible cube face in the original crystal. Photo by Junko Shida.

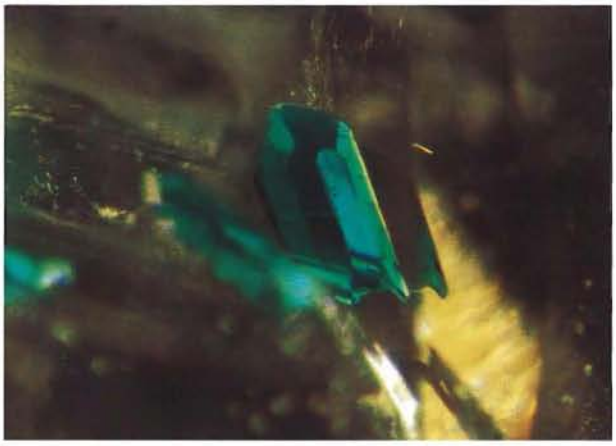


Figure 16. These colorful dioptase crystals in quartz from Congo are oriented along a growth plane in their host. Photomicrograph by Dr. Edward J. Gübelin; magnified 66×.

Sapphires and rubies from Laos. George Bosshart, managing director of the Gübelin Gemmological Laboratory, Lucerne, Switzerland, described corundum varieties found with black spinel and orange zircon in the gemstone placers of Ban Hua(e)i Sai (sometimes spelled Ban Houay Xai) in northwestern Laos, near the Mekong River and the Thai border.

Blue sapphire is the dominant gem material; however, because of sporadic production and limited quantities, this material has been absorbed by local markets rather than exported. These limitations, and the comparatively dark color of the stones, explain why Laotian sapphires have gone largely unnoticed thus far on the world market. In the past, up to six eluvial and alluvial gravel deposits have been mined in the hills and valleys behind Ban Houay Xai, usually by "independent" miners and with traditional extraction methods. The sapphires originate from nearby Quaternary alkali basalts.

Occasionally, Laotian sapphire occurs in good color. Some finished stones have weighed up to 10 ct. In addition to blue sapphires, violet-to-purple color-change sapphires and (contrary to earlier reports in the literature) small quantities of rubies in sizes below 10 mm recently have been confirmed from the open-pit diggings. Preliminary investigation of all three colors of Ban Houay Xai corundum—blue sapphires, color-change corundums, and rubies—revealed that all have properties consistent with a basaltic origin. The violet-to-purple stones appear more closely related to the rubies than to the blue sapphires, on the basis of very similar inclusions, absorption characteristics, and chemical compositions (Cr+V; (Fe+Ti)/Ga ratio). It is conceivable, therefore, that the rubies and fancy-color sapphires originate from another basaltic source in the same general area as the source for the blue sapphires.

A common problem encountered when heat treating Laotian and other basalt-associated sapphires is that of Fe^{2+}–Fe^{3+} intervalence charge transfer, which causes the gray (to black) tone typical of basaltic sapphires. However, greenish blue sapphires can be modified to light blue by a two-stage annealing (oxidizing/reducing) process, and dark blue colors can be improved somewhat by conventional heating with charcoal or petroleum. Saturated, attractive blue stones are not heat treated.

Mr. Bosshart has been studying various mineral inclusions in the Laotian corundums, using SEM, Raman, XRD, FTIR, and microscopic techniques. High-type zircon inclusions are ubiquitous and are commonly accompanied by columbite- and monazite-group minerals, albitic feldspar, rutile, graphite, and possibly apatite. Negative crystals in basal orientation, containing two-phase (fluid and gas) fillings, are surrounded by iridescent fluid rosettes reminiscent of those seen in Thai rubies.

George Bosshart confirmed recent reports of another ruby occurrence and placed it in southern Laos. He added that it is not the same as the corundum deposits recently detected in Vietnam along the Laotian border.

ENHANCEMENTS

Durability of polymer-impregnated (B-type) and natural jadeite. C. M. Ouyang, of the Hong Kong Gems Laboratory, reported on an "aging" test that she had performed on six natural jadeites and at least four polymer-impregnated (B-type) jadeite samples. Each jade sample was cut into pieces, with one piece of each retained for "before-and-after" comparisons. Samples were exposed to four types of durability tests: soaking in detergent, heating in an 80°C oven, exposure to a 40W daylight-equivalent light source, and exposure to ultraviolet radiation. After 90 days of each treatment, none of the natural

Figure 17. Part of the Guarrazar Treasure, this 11-cm-diameter gold crown has five sapphires and one iolite as drops. Photo © Patrimonio Nacional, Spain.

jadeites was affected; the B-jade samples were not affected by the lighting or UV radiation tests, were slightly affected by the heating tests, and were significantly affected by soaking in detergent.

For the detergent test, the B-type jadeites were soaked in a detergent solution (one part "washing" liquid to five parts water) for up to 90 days. The solution was stirred twice daily, and the material was examined at about two-week intervals. Surface polymer layers showed partial-to-nearly complete dissolution at the first examination (15 or 16 days); the boundaries between crystal grains became evident at 35 or 54 days (two samples); and two B-type jade samples appeared cracked at 40 and 73 days. Ms. Ouyang calculated that this corresponded to cracks appearing after 10 and 19 years' wear, respectively, if one submerged the jade in quarter-strength detergent solution (that is, one part detergent to 20 parts water) for one hour daily.

One of the four B-type jadeite samples exposed to heat showed a burn mark after 24 days at 80°C, but the others showed no change after 55 days of heating. In previous studies, Ms. Ouyang had found that B-type jadeite turns brown at 250°C, brownish black at 350°C, and "charcoal black" at 400°C (natural jadeite is unchanged by heating to these temperatures). None of the samples was affected by the tests for prolonged exposure to light or UV radiation, although more powerful sources might have produced different results.

INSTRUMENTATION

Infrared spectroscopy of Thai rubies and sapphires. Wilawan Atichat, from the Thai Ministry of Industry, examined FTIR spectra in transmission mode of 38 corundums from Chanthaburi-Trat and Kanchanaburi, in Thailand. She found seven different types of mid-infrared spectra for these samples, depending on the regions from which they came. Morphological and visual-characteristic studies of the inclusions were also correlated to the FTIR spectra. In fact, the variations present in the FTIR spectra were due mostly to inclusions (type, variety, size, shape, number, and assemblage), and were affected by the corundum chemistry to a lesser degree. With inclusion and chemistry information, these FTIR spectra could be used to determine the location from which the stones were derived.

Infrared spectroscopy distinguishes synthetic from natural emerald and quartz. In two presentations, Pierre Zecchini, of the Crystallography and Mineral Chemistry Laboratory at the University of Franche-Comté, Besançon, France, and co-workers explored the use of infrared spectroscopy to distinguish synthetic from natural materials. In the first of these talks, they asserted that spectroscopy of reflected IR radiation can be used to determine whether emeralds crystallized in nature or in the laboratory, and to separate emeralds from green beryls. Transmitted IR radiation can confirm the results from the reflected method, and it may also be used to determine whether an emerald has been impregnated.

Also covered was how infrared spectroscopy can separate natural from synthetic amethyst, citrine, and quartz of other colors. Each variety has its own typical spectra for natural and artificial crystallization; hence, the IR spectrum acquired for an unknown quartz example must be compared with standard spectra for the same variety (for instance, amethyst with amethyst; not citrine or some other variety with amethyst). Another part of this presentation concerned ametrine: Differences were seen between the compositions of the purple and yellow regions of natural ametrine. However, natural ametrine could not be clearly differentiated from ametrine obtained by heating natural amethyst.

MISCELLANEOUS

Gems from archeological excavations in Rome (Crypta Balbi)... Dr. Georgio Graziani, of the University of Rome, described his investigation with G. B. Andreozzi and L. Sagui of 28 gems coming from "Crypta Balbi," a Roman archeological site dating to the 7th century B.C. The identification of the materials was made more difficult by the fact that the samples had been poorly preserved and by the need for completely nondestructive (and, within limits, noninvasive) tests. Still, enough information was obtained to hypothesize about origin. The samples included a blue sapphire from Sri Lanka, an emerald from Egypt, and a piece of amber from the Baltic area. Also identified were quartz varieties (including rock crystal, carnelian, and sardonyx), as well as garnets, lapis lazuli, and corals.

... and gems in a Visigoth treasure. Cristina Sapalski, of the Instituto Gemológico Español, in Madrid, discussed gems from the Guarrazar Treasure. This hoard of 7th-century jeweled votive crowns (see, e.g., figure 17) and crosses was discovered in 1858 in the province of Toledo, Spain. The part of the hoard that was studied by Ms. Sapalski and her associate, Juan S. Cozar, included 243 blue sapphires, three cordierites (iolites; probably thought to have been sapphires), 14 emeralds, one aquamarine, two moonstones, nine rock-crystal quartzes, six blue chalcedonies, 21 amethysts, 169 pearls, 154 pieces of mother-of-pearl, 110 glass "stones" (green, blue, orange-brown, and of indeterminate color owing to later devitrification), and many small garnet fragments. All the sapphires had been polished, some were partially faceted, one was cut as a hollow cabochon, and one was engraved. The sapphires' gemological characteristics suggest that they came from the old Ceylon (now Sri Lanka) deposits.

ANNOUNCEMENTS

Treasures of Mexico exhibit at the Houston Museum. The Houston (Texas) Museum of Natural Science is hosting an exhibit of minerals, gems, and precious metals until September 8, 1996. "Mineral Treasures of Mexico: the Romero Collection of Gems and Minerals," includes over 200 pieces, most of which have never been seen outside Mexico. More information is available through the museum's World-Wide Web site, http://www.hmns.mus.tx.us.

LETTERS

SOME COMMENTS ON "A CHART FOR THE SEPARATION OF NATURAL FROM SYNTHETIC DIAMONDS"

In Box A of this article (Winter 1995 *Gems & Gemology*, pp. 256–264), I think there are some misleading statements about ultraviolet fluorescence of natural versus synthetic diamonds. The authors state that "A natural diamond typically fluoresces blue to long-wave UV (LWUV) radiation, with a weaker and usually yellow reaction to short-wave UV (SWUV). . . . 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."

My first comment: Blue is the most common fluorescence color in diamonds, but it is not typical, as many stones are visibly inert.

My second comment: The authors state that synthetic diamonds (all the stones and all the colors) fluoresce yellow to both LWUV and SWUV. I know that it is diagnostic for synthetic diamonds *not* to show a visible LWUV reaction, and to fluoresce yellow to SWUV; only a particular kind of colored synthetic diamond also fluoresces yellow to LWUV.

The authors' statements appear to contradict the chart (and the literature, too). I think an erratum is needed for further clarification.

Filippi Roberto, G.G.
Lucca, Italy

In Reply

We thank Mr. Filippi for taking the time to share his remarks, and we appreciate the opportunity to clarify this information for him and our readers.

With regard to his first comment, it is true that many diamonds are visibly inert when exposed to UV radiation. In our experience, however, *most* diamonds do luminesce when excited by ultraviolet light. As stated in Box A, it is important—*for identification purposes*—to observe the reaction with the stone in total darkness. Although the fluorescence of natural diamonds is often very faint, it does exist and typically is blue.

With regard to Mr. Filippi's second comment, we agree that, as stated, the text in the box and the chart may appear to be inconsistent. To clarify this matter, we should have added to the box text that *when present*, the fluorescence of synthetic diamonds (that is, *synthetic yellow diamonds*) to long-wave UV radiation is typically yellow.

It is interesting to note that whereas no LWUV fluorescence was visible in the synthetic yellow diamonds we first examined, those we have seen in recent years have often had a moderate to strong reaction. In rare instances, we have observed a very weak orange reaction to LWUV in some colorless to near-colorless synthetic diamonds.

James E. Shigley, Ph.D.
Director of Research, GIA Santa Monica

MAGNETIC PROPERTIES OF SYNTHETIC DIAMONDS

The recent article on separating natural from synthetic diamonds (Shigley et al., Winter 1995, pp. 256–264) recommends suspending the stone on a thread and causing it to swing as a magnet is moved close to it. Aside from the problem of fastening a thread to a small faceted gem, any movement of the stone requires that the stone be raised against the pull of gravity. Consequently, the larger the stone is, the lower the sensitivity will be, and mounted stones probably can't be tested at all.

However, if the stone is floated on a small plastic foam raft (e.g., a piece of a polystyrene cup) in water, the effect of gravity is eliminated and magnetic attraction will cause the raft to move toward the magnet. Finally, in the interest of historical accuracy and practicality, the "Magnetic Wand" rare-earth magnet ascribed to Alan Hodgkinson was developed by Hanneman Gemological Instruments, Poulsbo, Washington 98370. It is available for less than $15, a minute fraction of the cost of a cathodoluminescence instrument.

W. Wm. Hanneman, Ph.D.
Poulsbo, Washington

In Reply

Again, we appreciate Dr. Hanneman's comments and especially this opportunity to expand on our original article. Please note, first, that we usually do not rely on the property of magnetism for mounted stones. Second, clay or Blu-Tack make attaching a diamond to a thread rather easy. Third, when a diamond is suspended from a fine silk thread, virtually no vertical movement is needed to prove magnetism. Rather, magnetism is typically detected by a very slight side-to-side movement, especially when the thread is fairly long (12–15 inches). In many cases, a synthetic diamond reveals magnetism by pivoting on the thread when the magnet is moved in a semi-circular motion close to the stone. In this situation, even a weak magnetic reaction is detected and there is no vertical or horizontal movement, only a slight pivoting.

I have not personally tried Dr. Hanneman's method, but from my experience with the thread, I would anticipate that it also has pluses and minuses. The bottom line is that both methods are rather low tech and both probably work for most synthetic diamonds with metallic inclusions.

Thomas M. Moses, G.G.
Vice President, Identification Services
GIA Gem Trade Laboratory, New York

THE GEMS & GEMOLOGY MOST VALUABLE ARTICLE AWARD

Alice S. Keller, Editor

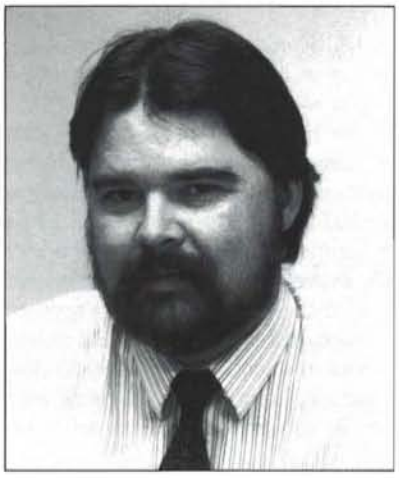
If the final vote tally for 1995's *Gems & Gemology* Most Valuable Article Award is any indication, diamond was the topic of the year. Articles about the (arguably) most valuable gem material—covering past, present, and future industry concerns—swept all three awards. Readers gave first place to the comprehensive wall chart and accompanying article—"A Visual Guide to the Identification of Filled Diamonds"—which deals with one of the modern diamond industry's most pressing problems. Authored by Shane F. McClure and the late Robert C. Kammerling, this article appeared in the Summer issue. The award for second place went to another tool to help prepare the industry for what may be the greatest challenge of the 21st century—"A Chart for the Separation of Natural and Synthetic Diamonds"—by James E. Shigley, Emmanuel Fritsch, Ilene Reinitz, and Thomas M. Moses. It has been said that we cannot judge our future without knowing our past, which is reflected in our readers' selection for third place, "A History of Diamond Sources in Africa: Part I," by A. J. A. (Bram) Janse. Both the second- and third-place winners appeared in the Winter issue.

The authors of these three articles will share cash prizes of $1,000, $500, and $300, respectively. Photographs and brief biographies of the winning authors appear below.

Congratulations also to Marcia Matthieu, of Palm Springs, California, whose ballot was randomly chosen from all submitted to win the five-year subscription to *Gems & Gemology*.

FIRST PLACE

SHANE F. MCCLURE
ROBERT C. KAMMERLING



Shane F. McClure

Shane F. McClure, with 18 years in gemology, is supervisor of identification services in the GIA Gem Trade Laboratory, Santa Monica. A contributing editor to both the Gem News and Gem Trade Lab Notes sections, and an author on many *Gems & Gemology* articles, Mr. McClure is also an accomplished gem photographer. The late **Robert C. Kammerling** was vice president of research and development at the GIA Gem Trade Laboratory, Santa Monica, and a regular contributor to gemological publications worldwide. An associate editor of *Gems & Gemology* and coeditor of the Gem Trade Lab Notes and Gem News sections, he coauthored—with Dr. Cornelius Hurlbut—the book *Gemology*.

Robert C. Kammerling

James E. Shigley

Emmanuel Fritsch

SECOND PLACE

JAMES E. SHIGLEY
EMMANUEL FRITSCH
ILENE REINITZ
THOMAS M. MOSES

James E. Shigley, who has a doctorate in geology from Stanford University, is director of GIA Research. He has written many articles on natural, treated, and synthetic gems, and directs research on all aspects of identifying and characterizing gem materials. Former manager of GIA Research **Emmanuel Fritsch** has returned to his native France, where he is now a professor of physics at the Gemology Laboratory, University of Nantes. He has an advanced degree in geological engineering from the Geology School in Nancy, France, and his Ph.D. in Spectroscopy from the Sorbonne in Paris. He has written more than 80 articles, most related to the application of spectroscopy to gemology, the origin of color in gem materials, and treated and synthetic gems. **Ilene Reinitz** is a research scientist at the GIA Gem Trade Laboratory in New York. A regular contributor to the Gem Trade Lab Notes section and coauthor of a number of *Gems & Gemology* articles, she has a B.S. in geochemistry from the California Institute of Technology in Pasadena and a Ph.D. from Yale University. Dr. Reinitz specializes in research into the origin of color in diamonds and the application of spectroscopy in gemology. **Thomas M. Moses**, with 19 years of trade and laboratory experience, is vice president of identification services at the GIA Gem Trade Laboratory in New York. A prolific author, as well as a contributing editor on the Gem Trade Lab Notes section, Mr. Moses specializes in pearl identification and origin-of-color determination for colored diamonds.

Ilene Reinitz

Thomas M. Moses

A. J. A. (Bram) Janse

THIRD PLACE

A.J.A. (BRAM) JANSE

Bram Janse has been involved in diamond exploration for 38 years, working on projects in Australia, Brazil, Canada, India, and South Africa. President of his own geological consulting company, Archon Exploration Pty Ltd, of Perth, Western Australia, he has a B.Sc. in geology and a M.Sc. in petrology and mineralogy from the University of Leiden in the Netherlands, as well as a Ph.D. in petrology from the University of Leeds in England. He is currently a director of KWG Resources in Montreal. In addition to his consulting work and many publications, Dr. Janse is working on an extensive database of diamond and kimberlite occurrences.

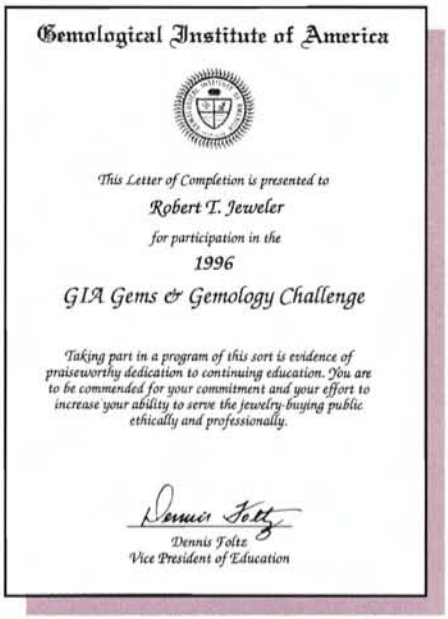
GEMS & GEMOLOGY

C·H·A·L·L·E·N·G·E

The 1995 volume year offered a broad variety of articles, ranging from historic localities such as Baja California for pearls and Turkey for meerschaum, to new ones such as Mong Hsu for rubies and Mali for garnets. In gem identification, however, the dominant concerns surrounded diamonds and especially the need for visual aids to help sort through the vast amounts of information that have become available in two key areas: (1) the identification of filled diamonds, and (2) the separation of natural from synthetic diamonds. Now, we invite you to test your knowledge of these important topics by taking the 10th annual *Gems & Gemology* Challenge.

The following 25 questions are based on information from the four 1995 issues of *Gems & Gemology*. Refer to the feature articles and Notes and New Techniques in these issues to find the single **best** answer for each question; then mark your choice with the corresponding letter on the response card provided in this issue (sorry, no photocopies or facsimiles will be accepted; contact the Subscriptions Department if you wish to purchase additional copies of the issue). Mail the card so that we receive it no later than Monday, August 12, 1996. Be sure to include your name and address. All entries will be acknowledged with a letter and an answer key.

Score 75% or better, and you will receive a GIA Continuing Education Certificate. Earn a perfect score, and your name will also be featured in the Fall 1996 issue of *Gems & Gemology*. Good luck!



Gemological Institute of America

This Letter of Completion is presented to

Robert T. Jeweler

for participation in the

1996

GIA Gems & Gemology Challenge

Taking part in a program of this sort is evidence of praiseworthy dedication to continuing education. You are to be commended for your commitment and your effort to increase your ability to serve the jewelry-buying public ethically and professionally.

Dennis Foltz

Dennis Foltz
Vice President of Education

Note: Questions are taken only from the four 1995 issues. Choose the single ***best*** *answer for each question.*

1. The vast majority of faceted Mong Hsu rubies found on the world market are
   A. oiled.
   B. dyed.
   C. glass filled.
   D. heat treated.

2. Fracture-filled diamonds can be detected routinely using
   A. spectral analysis.
   B. chemical analysis.
   C. magnetic attraction.
   D. basic microscopy techniques.

3. A clear and ready means for separating southern Vietnam sapphires from their synthetic counterparts is a combination of internal characteristics and
   A. X-ray diffraction pattern.
   B. microprobe analysis.
   C. chemical analysis.
   D. absorption spectrum.

4. Repopulating the Gulf of California's pearl grounds through artificial breeding was primarily the work of
   A. A. P. Cattet.
   B. Gastón J. Vives.
   C. Manuel de Ocio.
   D. Colonel Miguel L. Cornejo.

5. The internal growth structures of southern Vietnam sapphires are
   A. typical of most metamorphic corundum deposits around the world.
   B. identical to sapphires found in Pakistan.
   C. similar to other basaltic deposits around the world.
   D. unique, and useful in conclusively determining origin.

6. In the late 1600s, meerschaum was mined in
   A. Spain.
   B. China.
   C. Austria.
   D. Turkey.

7. Microscopic features characteristic of Czochralski-grown synthetic pink Ti-sapphire include

   A. gas bubbles and subtle color banding.
   B. metallic inclusions.
   C. evidence of twinning.
   D. none of the above.

8. Sepiolite can be easily carved as long as it is

   A. dry.
   B. cold.
   C. moist.
   D. heated.

9. The most consistently encountered diagnostic feature of fracture filled diamonds is

   A. flow structure.
   B. the flash effect.
   C. surface residue.
   D. trapped bubbles.

10. The emerald mines of Russia's Ural Mountains have been worked

    A. almost continuously since 1831.
    B. sporadically throughout the 20th century.
    C. very little between 1917 and the late 1980s.
    D. sporadically since the late 17th century.

11. The most common colors for Mali garnets appear to be

    A. greenish yellow to yellow-green.
    B. orange to red.
    C. bluish green to greenish yellow.
    D. yellow to orange.

12. Kokishi Mikimoto's early success in pearl-oyster cultivation was largely the result of

    A. appropriate environmental conditions.
    B. having information about Vives' work.
    C. extensive experimentation and research.
    D. refining methods and equipment to control the environment.

13. Sapphires were first discovered in Montana in

    A. 1865.
    B. 1889.
    C. 1892.
    D. 1895.

14. The GIA Gem Trade Laboratory calls Mali garnets by the name

    A. Mali garnet.
    B. grandite garnet.
    C. grossular-andradite.
    D. Mali grossular garnet.

15. Emeralds in the Urals are found

    A. in schists.
    B. in granites.
    C. as xenoliths in basalts.
    D. primarily as alluvial deposits.

16. If included crystals of a transparent mineral such as garnet or diopside are discovered in a diamond, the

    A. sample's origin is uncertain.
    B. diamond is natural.
    C. diamond is synthetic.
    D. diamond is of Russian origin.

17. Most Mong Hsu rubies can be separated from other natural rubies as well as from synthetics in part because Mong Hsu rubies

    A. are not zoned.
    B. do not have fluid inclusions.
    C. often display distinctive growth patterns.
    D. have a lower specific gravity than other rubies.

18. The diamond-producing nation that ranks first in the world in per-carat value is

    A. Zaire.
    B. Angola.
    C. Namibia.
    D. South Africa.

19 From 1889 through 1959, South Africa's proportion of worldwide diamond output was

    A. 50%.
    B. 75%
    C. 90%.
    D. 98%.

20. The height of pearl fishing in the Gulf of California was approximately

    A. from the mid-1700s to the mid-1800s.
    B. between 1800 and 1889.
    C. from the mid-1800s into the 1920s.
    D. between 1920 and 1970.

21. The largest transparent diamond found to date was the

    A. Jonker.
    B. Premier.
    C. Cullinan.
    D. O'Reilly.

22. When an unknown stone is suspected of being a synthetic Ti-sapphire, the most conclusive means of identification is

    A. birefringence or pleochroism.
    B. high magnification or immersion in methylene iodide.
    C. optic character or specific gravity.
    D. chemical analysis or UV-visible absorption spectrum.

23. When a diamond does not respond to a magnet, the

    A. test is inconclusive.
    B. diamond is natural.
    C. diamond is synthetic.
    D. diamond is fracture filled.

24. When attempting to separate natural from synthetic diamonds, the presence of hourglass graining is

    A. inconclusive.
    B. evidence that the diamond is natural.
    C. evidence that the diamond is synthetic.
    D. None of the above

25. Most gem-quality sapphires from Yogo Gulch are

    A. heat treated.
    B. noticeably included.
    C. larger than one carat.
    D. naturally well saturated and uniform in color.

BOOK Reviews

SUSAN B. JOHNSON AND JANA E. MIYAHIRA, EDITORS

SYNTHETIC DIAMOND: EMERGING CVD SCIENCE AND TECHNOLOGY

*By K. E. Spear and J. P. Dismukes (Eds.), 663 pp., illus., publ. by John Wiley & Sons, New York City, 1994. US$89.95**

Chemical vapor deposition (CVD), as used in the context of this book, involves the production of synthetic diamond from carbon-containing gases (CO, CO_2, CH_4, etc.) at low pressures (1 bar or less) and relatively low temperatures (<1000°C). All synthetic diamonds presently available commercially are produced at high pressures (>50 kbar) and high temperatures (>1400°C).

Although not well known, the first successful reproducible diamond synthesis by any method was, in fact, achieved by CVD in 1952: William G. Eversole, of the Union Carbide Corporation, grew a coating (film) of diamond on a substrate (seed) of natural diamond. Despite its early start, CVD research and development languished because of technical problems (e.g., extremely slow growth rates) and the rapid commercial development and success of the high pressure/high temperature process. Furthermore, at the time, CVD synthetic diamond could only be grown on a diamond substrate. Russian scientists made a major breakthrough in the mid-1970s when they grew CVD synthetic diamond on a nondiamond substrate. The modern era of CVD synthetic diamond began in the early 1980s, when Japanese researchers published methods by which rapid growth was achieved.

At present, the technology exists to deposit a coating of CVD synthetic diamond on many types of substrates (including various natural and synthetic gemstones). Although thus far there has been no report of large single crystals grown by CVD, vigilance is recommended because of the rapid advances in technology made over the past decade. Current production and consumption of CVD synthetic diamond materials is relatively small, but projections suggest that they are poised for rapid growth.

This comprehensive (through 1992) book covers all of the above topics and many more, in 16 chapters by different authors. It is intended primarily for professionals in material science engineering, solid-state physics, electronics, and optics, because diamond has superior properties for applications in these fields.

After an introduction (Part I) with a vision of the 21st century revolutionized by products made with CVD synthetic diamond, Part II traces the origins and emergence of the process in the USA, Russia, and Japan. Part III reviews the current scientific and technical status of the new CVD techniques, while Part IV looks at the fundamental properties (e.g., physical, electrical, optical) of diamond. The book concludes (Part V) with a review of potential industrial and technological markets for CVD synthetic diamond in the 21st century.

Even though some of the chapters are highly technical, most gemologists will be able to gain sufficient insight into the historical development and other aspects of CVD, and its potential effect on the diamond jewelry industry, to make this excellent book worthwhile.

A. A. LEVINSON, Ph.D.
University of Calgary
Calgary, Alberta, Canada

THE PEKING DIAMONDS

*By Peter Read, 208 pp., publ. by Gembooks, Dorset, United Kingdom, 1995. US$17.00**

Few authors have had the distinction of writing successful works of fiction based on a career in another field. With this book, Peter Read is a delightful exception. Having had a long and fruitful career as a gemologist and technical manager associated with De Beers, Mr. Read's knowledge of the diamond industry is unquestioned. Furthermore, the highly colorful and accurate descriptions of various locales reflect his many travels to gem-producing countries.

*This book is available for purchase through the GIA Bookstore, 1660 Stewart Street, Santa Monica, CA 90404. Telephone (800) 421-7250, ext. 282; outside the U.S. (310) 829-2991, ext. 282. Fax: (310) 449-1161.

Peking Diamonds is the second volume in Peter Read's diamond trilogy; the first, *Diamond Mine*, was reviewed by this author in the Winter 1993 issue of *Gems & Gemology*. From a literary standpoint—that is, plot and character development, pace, and action—this book holds up remarkably well and is highly entertaining. The characters are properly "fleshed-out," appearing very believable and even bringing into focus very modern problems within relationships. The plot creates the tension necessary to keep the reader involved, the pace is fast-moving, and there is a dramatic intensity to the action. The author tells the story well, riveting the reader's attention, and sets up some very believable settings.

From a gemological standpoint, the book is highly educational. The reader enters the inner rooms of the London Diamond Syndicate, visits the gem markets of Thailand, participates in trade commission visits to China and Moscow, and studies the technical aspects of manufacturing flux-grown synthetic gem crystals. Such details are illuminated with accurate and authoritative descriptions, which add to the believability of the story as they also pique the interest of the gemologist.

Although the book is, overall, both entertaining and educational, it is not without some minor faults. For example, the KGB agents in the story seem to lack finesse and are constantly "bungling" their operations, as in the inept timing of a murder in China and the London kidnapping event (the latter, involving a 24- to 36-hour vigil with the victims, should have been manned by at least six agents, not two). In both instances, a more complex treatment of the events could have intensified the drama. Also, there is a plot device that creates a believability problem for the gemologist: Would diamond buyers (or their cutters) really be fooled by flux-grown synthetic spinel octahedra that showed up in packets of diamond rough? Although the shape may approximate that of a diamond crystal, other characteristics would certainly separate the two materials (the quality of the transparency, typical markings found on rough diamonds, etc.). Such discrepancies, it seems, should have been caught early by sight alone, not by the cutting operations described in the story.

Nevertheless, the major elements of the story are sound, and the book is well worth reading, both by the general public and the gemologist.

JOHN D. ROUSE
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OTHER BOOKS RECEIVED

Colorado Rockhounding, A Guide to Minerals, Gemstones, and Fossils, *by Stephen M. Voynick, 372 pp., illus., publ. by Mountain Press Publishing Co., Missoula, MT, 1994, US$14.00* (paper).* Colorado is one of the nation's most interesting locales for the field collector. Part one of this book, "Collecting in Colorado," looks at the geology of the state, mining and digging activities, historical collecting areas, and legal and safety issues. Part two, "Collecting Localities and Related Sites of Interest," covers gold, mineral, fossil, and gem occurrences on a county-by-county basis, as well as such places as museums and rock shops. There is also a Colorado mineral guide, a glossary, references, and an index.

The book is easy to read and logically formatted. The author is strong on the history of mining in Colorado and on mineralogical data. The listing of locales is impressive, and the maps and directions far exceed the typical field-collecting guide. Unfortunately, the photos are only in black and white, and some of the photography and specimens are not of top quality. There are also some gemological errors, such as calling aquamarine the birthstone for October, and misapplying the term *fire* (dispersion) to the play-of-color phenomenon in opal. Nevertheless, the book is useful and informative.

MICHAEL T. EVANS
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Mineral Books, *a special issue of* Mineralogical Record, *Vol. 26, No. 4, July-August 1995, 256 pp., illus., publ. by Mineralogical Record, Tucson, AZ, 1995, US$24.00* (hardcover with supplementary text, US$49.00*).* This special issue covers a broad range of topics: collecting, medieval mineralogy, gem minerals in early Arabic literature, a history of systematic mineralogies (brought up to date), and a series of articles on such landmark works as D'Agoty, Rashleigh, Sowerby, and Koksharov, with several of their plates reproduced here in color. An extensive list of books and other publications dealing with regional mineralogies, the history of the now-defunct *Mineral Digest*, a large illustrated article on mineralogical bookplates, a review of Sinkankas' *Gemology—An Annotated Bibliography*, and a note on the *Mineralogical Record* library complete the issue.

Of particular interest to gemologists is the section on medieval mineralogy, which should have been labeled "Medieval Gemology," because most of the books reviewed therein deal with lapidaries. This essay, written by F. D. Adams, was originally published as Chapter V in his *Birth and Development of the Geological Sciences* (1938). The article by W. J. Sersen on Arabic gemological writings is also interesting and valuable. Sersen notes that most of the Arabic literature in his field remains untranslated.

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GEMOLOGICAL ABSTRACTS

C. W. FRYER, EDITOR

COLORED STONES AND ORGANIC MATERIALS

The co-precipitation of Fe^{3+} and SiO_2 and its role in agate genesis. T. J. Moxon, *Neues Jahrbuch für Mineralogie Monatshefte*, No. 1, 1996, pp. 21–36.

This article reports detailed experimental work on the use of Fe^{3+} and Mg^{2+} in removing H_4SiO_4 and colloidal silica from separate dilute silica solutions and sols (a suspension of solid particles of colloidal dimensions in a liquid) over periods of 45 minutes to 14 years. It is demonstrated that Mg^{2+}-SiO_2 gels in an alkaline saline environment at room temperature can develop signs of transformation into opal-CT after 14 years. The concentrations of Fe^{3+} found in some agates is considered to be coincidental and too low to precipitate silica from any silica sol or solution. *RAH*

extraLapis. No. 9, 1995.

The four groups of articles (all in German) in this special issue offer comprehensive and up-to-date information on many aspects of garnets.

The first group starts with a glossary of 72 garnet terms (from *Achtarandit* through *Rainbow Garnet* to *Zimtstein*) and a summary table of the garnet group. The chemistry and crystal structure of garnets are then described, including discussion of an easy way to calculate the relationship between the composition of garnets and their specific gravity and refractive index. Although rather technical, this article is easily understood, even by those who normally despair when faced with crystallographic details and chemical and mathematical formulas. Detailed descriptions of almandine, andradite, grossular, pyrope, spessartine, and uvarovite complete the first group of articles. Each description contains the mineralogical characteristics, gemological aspects, and a list of the most important deposits.

The first article in the second group focuses on the almandine garnets in the Austrian Alps (Tauernfenster), especially in Zillertal: their formation, their value for geologic research (measurement of age, pressure, and temperature), their mining, and their use in jewelry. The second article describes interesting hessonites from Piemont which have "fibers" comparable to those seen in some quartz crystals.

The third group of articles traces the history of garnet jewelry from antiquity to modern times. One article

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.

Inquiries for reprints of articles abstracted must be addressed to the author or publisher of the original material.

The reviewer of each article is identified by his or her initials at the end of each abstract. Guest reviewers are identified by their full names. Opinions expressed in an abstract belong to the abstracter and in no way reflect the position of Gems & Gemology *or GIA.*

discusses the origins of the names *garnet* and *carbuncle*, the important role of garnets (especially almandines), and the setting techniques used in early medieval jewelry. Outstanding examples of 17th and 18th century garnet goblets, cameos, and intaglios are described in the second article. The third article is a review of the pyrope deposits, mining, and jewelry manufacture in Bohemia from the 14th century to the present.

The articles in the last group again deal with more-technical aspects. The first covers production of synthetic garnets (especially YAG and GGG) and their many technical applications. The second article discusses the causes of color in garnets, including color-change garnets and the possible existence of blue garnets.

In addition to the wealth of valuable information, this issue is beautifully illustrated with 23 black-and-white and more than 120 color photographs. *RT*

Precious potential. G. Dick, *American Jewelry Manufacturer*, Vol. 40, No. 8, August 1995, pp. 18, 20, 22.

"Rubies and sapphires—gems of royalty for centuries—are now available to volume manufacturers in quantities and qualities beyond the dreams of ancient kings," says Ms. Dick in the opening sentence to this article. However, if "dreams of ancient kings" were for stones of great color, clarity, and size, such is not now the case. True, ruby supply is better than it has been for years, according to the International Colored Gemstone Association (ICA). But, as the author notes, today it is so much harder to find great stones in larger sizes that cutters in several world centers are concentrating on smaller, mostly commercial goods. It is the same story for sapphires: There is a seemingly endless supply of dark-blue commercial material in sizes under half a carat, but only a few mines are producing larger stones. This article also briefly discusses other sapphire colors and their availability.

Large quantities of commercial-quality rubies and sapphires will benefit everyone—manufacturers and consumers alike. For manufacturers, the large quantities enable them to produce volume jewelry at low prices. For consumers, this means a larger variety of jewelry at very affordable prices. *Anne M. Blumer*

DIAMONDS

Archaean Re-Os age for Siberian eclogites and constraints on Archaean tectonics. D. G. Pearson, G. A. Snyder, S. B. Shirey, L. A. Taylor, R. W. Carlson, and N. V. Sobolev, *Nature*, April 20, 1995, pp. 711–713.

Mantle-derived eclogite xenoliths erupted by kimberlites theoretically could tell us a lot about conditions on the early Earth, since they may be the remnants of an early (over 4 billion years) magma ocean of subducted Archaean crust or of crystallized high-pressure magma melts. Age dating can differentiate between these two cases.

Rhenium-osmium (Re-Os) isotope data for diamond-bearing eclogites from the Udachnaya kimberlite pipe give formation ages of 2.9 billion years (plus or minus 400 million years). Although these rocks are too young to tell us about early differentiation of the Earth, they do indicate that the crust was at least 150 km deep (the minimum thickness required for diamond formation) by the Mid-Archaean era. These results are consistent with an age of 2.7 billion years derived from data on lead isotopes in eclogitic clinopyroxenes separated from other Udachnaya xenoliths.

Such relatively young ages imply that these xenoliths are not related to early crust formation 4 billion years ago. Rather, they are related to craton formation in the Archaean era. (Note that other diamond inclusions [from South Africa] are Proterozoic in age, and eclogites from any one locality may have different ages.) The trace elements and oxygen isotopes in these Siberian xenoliths are consistent with an origin as oceanic crust that underwent low-temperature hydrothermal alteration; it may have been subducted during the Archaean era. *MLJ*

Best friend hides deep secret. W. M. White, *Nature*, January 11, 1996, pp. 117–118.

On the basis of the study of inclusions in diamonds, among other things, it has generally been accepted that once a continental mass forms, a region of mantle down to depths of 200 km (or more) is "frozen in" below it. Although most diamond inclusions come from the mantle (some apparently from the lower mantle—depths greater than 650 km), a crustal mineral (staurolite) has been found as an inclusion in diamond. In fact, staurolite is not even stable at the depths necessary for diamond to form, so this inclusion must have either: (1) occurred in a low-silica environment with silica present, staurolite reacts to form kyanite and garnet); or (2) been stored, possibly as an inclusion in a garnet (and so protected from reaction), before its current encapsulation in the diamond.

Although this inclusion is the clearest evidence that crustal material can come into contact with diamond-producing environments, it is not the only evidence. Some diamonds have carbon isotopes consistent with derivation from crustal carbon; in addition, kyanite, coesite, corundum, and alkali feldspar—all common minerals in metamorphosed crustal rocks—are found as inclusions in diamonds. Thus, it seems that in diamond-forming regions, the mantle may retain regions of incomplete mixing due to subducted crustal material. *MLJ*

De Beers, diamonds and the deep blue sea. A. Wannenburgh, *Optima*, Vol. 41, No. 2, 1995, pp. 24–29.

This article describes how De Beers Marine (Debmarine) mines diamonds in waters deeper than 100 m. Such mining is economically significant; for instance, 407,000 carats of gem-quality diamonds—31% of the total production of Namdeb (an equal partnership between Namibia and De Beers)—were recovered from deep waters off Namibia in 1994. Debmarine is also investigating deep-sea mining areas off the Namaqualand coast of South Africa and is sampling off Sierra Leone.

Offshore Namibian diamonds are concentrated in gullies and gravel "lag" deposits, seldom more than a few meters thick, which became submerged as ocean levels rose after the ice ages. Using a drilling ship and then a harbor dredge to collect samples in water up to 30 m deep, De Beers first explored these deposits in the early 1960s. As the diamondiferous gullies trended into deeper water, more-sophisticated mining vessels were developed. Debmarine, which was formed in 1983, devised a mining ship (the *Louis G. Murray*) with a remote-controlled underwater crawler to bring up diamond-bearing gravels from depths down to 200 m. Commissioned in 1987, this ship is still in use.

A less-expensive alternative for ocean-floor mining is the ship-mounted drilling platform. Rotary drill bits chew up the ocean floor in 0.5-m-diameter chunks; the global positioning system (GPS) is used to determine the position of the drill holes; and ship-based plants handle the ore. Gravels are "air-lifted" through the drilling pipe to a ship and screened (with the >19 mm and <2 mm fractions discarded). The remaining gravel is separated into fractions with densities less than and greater than 3.0 (diamond has a density of 3.5), and then sorted again into X-ray fluorescing (including diamond) and nonfluorescing fractions. The final concentrate is 20%–30% diamond. It is sealed on the ship for later sorting. *MLJ*

Diamonds. *Metals & Minerals Annual Review*, 1995, pp. 26–27, 30.

Industrial diamonds. *Metals & Minerals Annual Review, 1995*, p. 88.

The Central Selling Organisation (CSO) sold US$4.3 billion of rough diamonds in 1994, down slightly from US$4.4 billion in 1993. An estimated US$700–$800 million of Russian rough was sold outside the CSO agreement. World retail sales of diamond jewelry rose 4% (by U.S. dollars) in 1994 over 1993. (These two mining reports rely heavily on figures provided by De Beers.)

De Beers continued to work in partnership with local governments, including: restructuring CDM into the new firm Namdeb (Namibia), mining in partnership with the Botswana government (Debswana), negotiating with Angola and Sierra Leone, and prospecting in Canada.

In South Africa, the Finsch mine produced 2.3 million carats (Mct), the Kimberley mines produced 600,000 carats (including 40,000 carats from mine-dump reworking), Koffiefontein produced 120,000 carats, the Namaqualand mines produced 700,000 carats, the Koingnaas complex (Koingnaas and Mitchells Bay plants, including surf-zone production) produced 400,000 carats, the Premier mine produced 1.7 Mct, and the Venetia mine produced 4.9 Mct. The total South African production of 10.2 Mct was below capacity, and a cost-containment program remained in effect.

In Namibia, the Elizabeth Bay region produced 100,000 carats, and marine production totaled 1.3 Mct. Botswana production in 1994 was 15.6 Mct. Angola may have produced 1.4 Mct in 1994, but the exact amount was hard to estimate because much of the output was smuggled out of the country.

Russian diamond production for 1994 was estimated at 11.5 Mct, primarily from Sakha (Yakutia); some interesting primary deposits have also been discovered in the Arkhangelsk and Perm regions. About half of Russian diamond production went to domestic cutting plants. Exploration and development continued in Canada in 1994, but there was no actual diamond production.

World diamond production rose to 107.5 Mct in 1994, from 101 Mct the previous year. In Australia, Argyle produced 42.8 Mct and Bow River produced another 200,000 carats. Zaire produced 18 Mct, including 12–15 Mct from small-scale diggers, most of which was probably smuggled out of the country.

World industrial diamond sales for 1994 were estimated at US$550 million; synthetic diamonds accounted for 90% of this total. At the end of the year, there was an oversupply of industrial-diamond products on the market, but demand for superabrasives in developing countries was increasing. *MLJ*

Diamond encouragement for Ashton. *Mining Journal, London*, July 28, 1995, p. 60.

Ashton Mining Ltd. has reported results from several joint ventures in Russia, Finland, Australia, and Mali. Kimberlite indicator minerals are being collected for analysis in Karelia, western Russia. "Mini-bulk sampling" has begun for three kimberlite pipes in Finland, with 26.6 carats per 100 tons reported from sampling Pipe 21, and 25.7 carats per 100 tons from Pipe 7. Bulk sampling is under way at Merlin in Australia's Northern Territory, with 200 tons of kimberlite ore collected for analysis.

In Mali, exploration by other companies identified a 2,000 km^2 kimberlite field in the Kéniéba region, in which 21 kimberlite pipes are known. Ashton expected to begin sampling a 36,000 km^2 neighboring region in October. *MLJ*

Distribution of luminescent centres in Yakutian diamonds. V. Mironov and B. Antonyuk, *Archiwum Mineralogiczne (Polska Akademia Nauk)*, Vol. 50, No. 2, 1994, pp. 3–12.

The laser-luminescence tomography method for revealing crystal zoning has been used to examine diamonds collected from the Malobotuobinskoe field in the Mirnyy region of Yakutia, Russia. This nondestructive method shows the distribution of luminescence centers in the crystals, usually arranged in zones formed during successive stages of growth. "Phantoms" (i.e., luminescent outlines of the growth zones) in diamond crystals provide information on changes in crystallization conditions in the parent rock. The method has been developed for use in the classification of diamonds from both primary kimberlite and secondary alluvial deposits in the Mirnyy region. The paper is illustrated with nine color photographs of yellow, green, and blue UV luminescence. *RAH*

Fossicking for diamonds in the Copeton area, part one. J. Tottenham, *Australian Gold Gem & Treasure*, Vol. 10, No. 3, March 1995, pp. 32–37.

In the late 1880s to early 1900s, diamonds were mined commercially in the Copeton area, about 23 km by road southwest of Inverell, in New South Wales, Australia. The author began "fossicking" (amateur collecting) for diamonds in this area many years ago while investigating the suitability of sand and gravel deposits there for concrete manufacture. The Copeton area is rich in alluvial sediments; in the 1970s and 1980s, exploration unsuccessfully sought hard-rock sources for the diamonds.

Total "official" diamond production in this area up to 1973 was 168,000 carats, but as many as 300,000 carats may have been mined there. (Alluvial tin is also found in the Copeton region, and has been of greater economic value historically.) The diamonds averaged 4 per carat (25 points each). Although most are industrial quality, the author thinks they make attractive mineral specimens. He describes them as unworn transparent crystals with high surface luster, usually yellow to white (but also pale pink, green, or brown). Complex twins are common, and "classic" octahedra are rare.

The diamonds are found in Tertiary river gravels (leads), many of which are covered by later basalt flows. At least two separate fossil river systems occur at Copeton, and diamonds are found in both channels. Gently falling "modern" creeks that cut through these leads may have workable concentrations of diamonds in their beds.

Some controversial evidence points to a dolerite (diabase) dike—not kimberlite—as being the source rock for the Copeton diamonds; this evidence includes a specimen of diamond in dolerite matrix. Regardless, typical kimberlitic-diamond indicator minerals (pyrope garnet, chrome diopside, and nickel-rich ilmenite) are not present in Copeton.

This admittedly nontechnical article gives tips on how to recognize diamonds at Copeton. The most amusing of these is the (quintessentially Australian) "beer glass test." Drop a diamond and a similar-sized look-alike stone, such as a topaz, into a glass of beer from rim height. The diamond should bounce around "like a super ball," while the other stone should not. As a conscientious reviewer, I regret that I have not yet tried this test. *MLJ*

Recent deformations of the deep continental root beneath southern Africa. L. P. Vinnik, R. W. E. Green, and L. O. Nicolaysen, *Nature*, May 4, 1995, pp. 50–52.

One way to determine the nature of Earth's upper mantle is to examine xenoliths brought up from great depths by geologic forces; another is to bounce sound- or shock-waves off layers in the Earth. The authors studied the mantle beneath the Kaapvaal craton of South Africa using the latter technique. They conclude that the mantle in the region between 150 and 400 km beneath this craton flows in a direction parallel to plate motions in modern times (i.e., the last 200 million years). The old continental root beneath the craton must be deformed by the plate motion.

Silicate inclusions in diamonds from the Kaapvaal craton have been dated as Archaean in age—significantly older than 200 million years; we would expect to see young inclusions in Kaapvaal diamonds if the diamonds were: (a) coming up through the crust in recent times (the last few hundred million years), and (b) sampling the region where the mantle is flowing. The authors argue that (b) is not the case: Kaapvaal craton diamonds sample the mantle and craton root at depths shallower than 200 km, and most of the mantle flow occurs at a depth greater than this. *MLJ*

Russia's diamonds: 40 years of mettle. R. Shor, *Jewelers' Circular Keystone*, Vol. 166, No. 10, October 1995, pp. 78–81.

While attending a diamond summit in Moscow in June 1995, leaders of the international diamond community toured the Mir and Udachnaya diamond mines in the republic of Sakha. Production figures and mining processes for each deposit are reviewed. Their remoteness and the incredibly harsh natural conditions create special problems at each mine, which are described in detail. Industry delegates also visited the diamond museum in the town of Mirnyy, which provides the history of the mining areas.

Privatization and problems at the mines have cut the workforce drastically, and environmental concerns have prevented startups at new locations. The government is optimistic, however, pointing to 50 polishing factories and the rapid growth of towns like Mirnyy and Udachny. Although many in the trade are skeptical that Yakutsk (the capital of Sakha) will become a major diamond hub, the government has proposed creating a large diamond cutting and polishing center there. *JEC*

GEM LOCALITIES

Bulk opal mining a Qld first. *Queensland Government Mining Journal*, Vol. 96, No. 1123, August 1995, p. 27.

Three gem-quality black opals were discovered in August 1994 at the Hebel tenement, in Queensland, Australia, 90 km north of Lightning Ridge. This prompted the leaseholder, Redfire Resources, to begin bulk sampling at Hebel. Open-cut mining has been used to remove overburden, up to 30 m thick, followed by large-scale drilling to identify zones in the clay-seam target areas that have high concentrations of opal. Bulk methods can be used at Hebel because the claim area is large (400 km^2); at Lightning Ridge, individual claims are limited to 50×50 m, which is too small for bulk-mining techniques. *MLJ*

Connecticut: Gems & gem minerals. B. Jarnot, *Rocks & Minerals*, Vol. 70, No. 6, 1995, pp. 378–382.

Most gem-quality minerals from Connecticut were discovered during the first half of this century, when various mines, quarries, and prospects were being actively worked. Although many of the famous localities are now

closed to collectors, several of Connecticut's finest gem specimens are in the university collections of Harvard, Wesleyan, and Yale.

Jarnot describes characteristic material from notable localities, quoting old accounts of tourmaline from the Strickland quarry, Gillette quarry, and the Brack prospect. Many green crystals from the Strickland quarry were reportedly sold to Tiffany's and to rock shops in Maine (where they were mistakenly called "Maine tourmalines"). The Gillette quarry became world famous for its beautiful specimens of pink-and-green "watermelon" tourmalines. Such "watermelon" tourmalines were also frequently encountered at the Brack prospect, but that locality is noted more for crystals with a distinctive deep blue "cap" on pedion terminations.

Considerable quantities of pale yellow to "golden" brown heliodor, and pale to medium green aquamarine, were recovered at the Roebling mine. The Slocum and CCC quarries also produced heliodor, and the Pelton quarry was known for its well-formed, deep blue aquamarine crystals. The Swanson gem mine produced morganite as well as heliodor. Several pounds of high-quality pink-to-peach morganite, green-to-blue aquamarine, and colorless goshenite were recovered from the Brack prospect.

Jarnot notes other localities for topaz, quartz, garnet, and spodumene, as well as for collector specimens of cordierite, pollucite, datolite, fluorite, oligoclase, and prehnite. All specimens pictured are from the author's comprehensive personal collection of Connecticut gems and minerals. *LBL*

Connecticut mineral locality index. M. H. Weber and E. C. Sullivan, *Rocks & Minerals*, Vol. 70, No. 6, 1995, pp. 396–409.

Connecticut, "a small state that is big on mineralization," boasts hundreds of different minerals throughout its eight counties. This index is a basic guide to the names, spellings, and locations of sites where the most significant minerals have been found.

The main index presents the locations (with the minerals noted) in alphabetical order within each county. Type minerals are noted at their type location. Another, smaller index alphabetically lists the localities by name, with their county of origin or alternate names in parentheses. The article includes an extensive bibliography and 28 color photos of mineral specimens. *LBL*

Finders keepers? Not in NSW. N. Keating, *Australian Gold Gem & Treasure*, Vol. 10, No. 5, May 1995, pp. 22, 24, 26.

The New South Wales (NSW) Mining Act was amended in 1992; new rules limit the amount of gold or gemstones that can be collected and retained by amateurs (fossickers) over 48 consecutive hours. Gold is restricted to 30 g (increased from 10 g in October 1994) and gemstones to 20 g (100 ct). The author notes further limitations under this act, including the fact that large individual stones (or nuggets) cannot be legally collected; that all gemstones have the same 100 ct limit, including "semi-precious" stones such as agate; and that composites such as matrix opal and gold-in-quartz are not defined. Those who collect illegally can be fined up to Aus$1,000. However, the NSW Department of Mineral Resources lacks sufficient personnel to enforce these laws, so the chance of being fined is very slim. Another problem with fossicking in Australia is that different states (and the Northern Territory) have different collecting laws. The author concludes with a plea for uniform, logical legislation. *MLJ*

Jantar: World centre of amber production. *Europa Star*, No. 201–3, 1995, p.104.

The Sambia Peninsula lies along the border between Poland and Kaliningrad, an "extraterritorial" section of Russia (Belorus and Lithuania lie between Kaliningrad and the bulk of Russia). In the sands of the Russian part of the Sambia Peninsula, up to 700 tons of amber are excavated annually; this represents 90% of world amber production. Most of this amber is processed in the Gdansk area of Poland. *MLJ*

More Benitoite locality information, another new one and another discredited [letter]. *Mineral News*, Vol. 11, No. 8, August 1995, p. 9.

In a letter to the editor, reader Alfredo Petrov straightens out some misconceptions in the mineralogical literature about benitoite localities. References to localities in the Owithe Valley, Belgium, and in southwest Texas are incorrect, he says. A reported locality in Hashidate Kanayame, Niigata prefecture, west-central Japan, produces blue six-sided crystals in a riebeckite-albite rock in serpentinite.

This letter revises the lists of known benitoite localities outside San Benito County, California, to include the Japanese site; New South Wales, Australia; and Magnet Cove, Arkansas. *AC*

And NUTS to you, too. P. O'Brien, *Australian Gold Gem & Treasure*, Vol. 10, No. 10, pp. 26–29.

A "Yowah nut" is an opal formation from what is loosely called the "boulder opal" family. Boulder opal fills the cracks, cavities, and nodules in the host rock. The opal-filled nodules—which typically appear as small, round ironstone balls—are usually called "Yowah nuts." Although they normally range from pea- to grapefruit-sized, the "Spirit of Yowah," discovered in 1993, is one-and-a-half times the size of a basketball and weighs just under 100 kg. "Yowah nuts" are found with greatest frequency in the ironstone and sedimentary rock around the small town of Yowah, Queensland, Australia.

The author reports on the find of the "Spirit of Yowah," and then relates good potential locales for opal rockhounds (called "fossickers" in Australia) in the Yowah area, as well as mining claims that are open to the general public. The report continues in the next issue of the magazine. *AC*

Rubies, sapphires and ball-point pens—small-scale gem mining operations in Sri Lanka. C. Hunt, *Geoscience and Development*, No. 2, May 1995, pp. 10–12.

On the basis of a three-day trip into the Central Highlands of Sri Lanka, the author describes the economy of small-scale gem mining in this island nation. The search for gemstones in alluvial deposits is a mainstay of Sri Lanka's economy. The earliest mention of gems in Kandy libraries dates back to the Buddhist period (624–544 B.C.), although this manuscript may refer to gems in India. However, Sri Lankan gemstones were certainly well known by Marco Polo's time. The Mineral Survey of Ceylon was established in 1903.

Almost all Sri Lankan gem deposits are in the Central and Southern Highlands regions, originating from either pegmatite dikes or their Precambrian metamorphic rock hosts. Because of high rainfall and intense weathering, the resistant gems concentrate in alluvial sediments, which cover 20% of the island. Gems found include corundum (ruby and sapphire), chrysoberyl, topaz, moonstone, and beryl, among many others.

For 2,000 years, mining knowledge—such as extraction techniques and the location of good mining sites—has been passed down by word-of-mouth. Mines are controlled by families or small consortia. A typical mine consists of a single shaft, about 2–3 m^2, that descends some 20–40 m to a small supported annex; the work face is found at the edge of this annex. Gravels from the work face are washed and concentrated using water removed from the mine shaft by "the only essential piece of modern equipment"—a gas-driven pump. The final step in gem recovery is panning the gravel. Some miners pan modern river gravels; however, these do not have gem concentrations as high as the older gravels found well below the surface.

Regardless of the mining technique used, the workers remain very poor, even when they own the land. At the various sites, children sell fragments of gems for school pens and similar trinkets. The author suggests that with modern extraction methods more gems could be found; with better record-keeping, worked-out areas could be avoided. In a 1993 *Gems & Gemology* article, Rupasinghe and Dissanayake generated a "gem-probability map," on which more than 5% of Sri Lanka is presented as being "highly probable" for finding gems and more than 21% as having a reasonable possibility. This map could be useful in establishing a more-efficient corporate mining program, but such a program might lower gemstone prices to the point where many of the small-scale miners now involved in this industry could no longer be supported by it. *MLJ*

The SA mineral industry: 1—The geological background. *Mining Magazine*, Vol. 172, No. 5, May 1995, pp. RSA 6–7, 9.

This review article describes the geology of South Africa as it relates to the ore deposits that have been found there, some of which are relevant to gemologists. Most of South Africa sits on the Archaean (up to and possibly more than 3 billion-year-old) Kaapvaal craton, a terrain built up of gneisses, granitoids, and lesser amounts of metamorphosed volcanic-arc-related rocks (greenstones). The greenstones host many economically important ore deposits, including gem minerals; corundum is sometimes found in the gneisses and granitoids. Karsting (cave formation) in 2.1-to-2.6-billion-year-old dolomitic rocks —in the Griqualand West area near Kuruman and Hotazel—resulted in the manganese deposits there (with associated sugilite and gemmy rhodochrosite crystals, among other minerals); nearby banded iron formations host amphibole asbestos and its silicified replacement, tiger-eye. The Premier diamond pipe was emplaced into the Kaapvaal craton 1.3 billion years ago; fragmentation of the Gondwana "supercontinent," which began less than 200 million years ago, was also accompanied by the emplacement of kimberlites, especially in the Kimberley area. *MLJ*

Semi-precious gem mining in southern Brazil: In view of the environmental aspects. B. Grimm and M. Priester, *Small Mining International Bulletin*, No. 8, February 1995 (no page numbers).

Gemstone mining in many regions of Brazil traditionally has been performed by *garimpeiros*, small-scale miners. In the amethyst- and agate-mining region in the northern part of Rio Grande do Sul State, each mine, or "garimpo," usually belongs to a working cooperative of landowners, owners of mechanical equipment, and garimpeiros. Legal reorganization in Brazil in the late 1980s resulted in new laws governing these mines. In particular, applications for concessions must be approved by the Brazilian mining authority (DNPM), and mining grants in Rio Grande do Sul are only valid when sanctioned by the appropriate environmental authority.

These environmental laws have two components: (1) protection of the physical environment (the land surface, water, and air quality, and local forests), and (2) protection of the health and safety of workers in the mines and processing facilities. Protection of the physical environment in this quartz-mining area is relatively simple. Because of the lack of capital and the independent nature of the miners' work, however, it is difficult to enforce safety regulations. Use of personal protective equipment (helmets, work boots, dust masks, etc.) promises more effective protection to both miners and processing-facility workers. *MLJ*

Spotlight on Namibia. *Mining Journal, London*, June 30 1995, pp. 484–485.

This brief article concentrates on prospects for economic development in all sectors of Namibia's mining industry. Gem exports in 1994 included sodalite (725 tons exported, at a total value of US$840,000); other "semi-precious" stones, including tourmaline and several varieties of quartz (947 tons; US$390,000); and especially diamonds (1,130,768 carats; US$384 million).

A significant portion of the diamonds mined in Namibia come from offshore deposits. In November 1994, Namdeb Diamond Corporation was formed—an equal partnership between De Beers and the Namibian government. Also in 1994, De Beers Marine, acting as contractor to Namdeb, recovered 407,000 carats from the concession south of Luderitz. It was expected to recover much more by 1996. Also, from the end of next year, an additional 100,000 or so carats could be mined by three new operators: Ocean Diamond Mining (recovering stones from shallow waters surrounding the 12 "Guano islands"), BHP/Benguela (the Diamond Fields Resources [DFR] concession offshore from Luderitz), and Namibian Minerals Company (Namco; adjacent to the DFR holding).

The Geological Survey of Namibia is creating a series of 1:250,000 magnetic and radiometric maps of the entire country, which should facilitate exploration for more resources. It has also developed an in-house mineral information database, NAMDAT.

Mineral collectors take note: Reserves at the Tsumeb copper mine are "virtually exhausted." In addition, the nearby Tschudi copper deposit will probably be mined by solvent extraction, a method that dissolves rather than produces mineral specimens. *MLJ*

Ein Trapiche-Rubin aus Myanmar (Burma) [A Trapiche Ruby from Myanmar]. H. -J. Müellenmeister and J. Zang, *Lapis*, Vol. 20, No. 12, 1995, p. 50.

Highlighting this brief article are two color photos of a ruby from Mong Hsu (Myanmar) that strikingly resembles trapiche emeralds in form. The separating "walls" between the ruby segments are mainly composed of calcite and ankerite, which were probably incorporated into the crystal on the planes with the highest growth rates. A trapiche sapphire was also found recently at Mong Hsu, so more of this beautiful new type of corundum may soon appear in the literature. *RT*

Turquoise from the Urals-Paikhoy region [in Russian with English abstract]. V. L. Silaev, L. A. Yanulova, A. V. Kozlov, and V. P. Ljutoyev, *Proceedings of the Russian Mineralogical Society*, Vol. 124, No. 6, 1995, pp. 71–86.

Detailed descriptions are given of the composition and properties, including crystal structure, of turquoise from the Paikhoy region of the Polar and Subpolar Urals. Chemical analyses for 29 turquoise specimens from this area are tabulated and compared to data from the literature; estimates are made for the degree of filling of the octahedral sites in the structure by Cu^{2+} and Fe^{3+}, on the basis of both electron microprobe and electron paramegnetic resonance data. The frequencies of principal absorption bands in the infrared spectrum of turquoise from the Urals-Paikhoy region are tabulated, and various hypothetical schemes for the isomorphous replacement of cations in turquoise are proposed. *RAH*

Zaire diamond exports rise. *Mining Journal, London*, September 15, 1995, p. 195.

Zaire exported 9.6 million carats (Mct) of diamonds in the first half of 1995, up from 7.8 Mct for the same period in 1994; the value of these exports rose from US$116.9 million to US$177.9 million. Of the 9.6 Mct, 2.1 Mct came from major producer MIBA, while 7.5 Mct came from agencies that purchase diamonds from small-scale producers. MIBA reportedly will provide diamonds directly (that is, bypassing the CSO) to the Indian cutting and polishing company, International Diamond Services; over US$37 million of diamonds are expected to be exported through this channel annually. *MLJ*

INSTRUMENTS AND TECHNIQUES

Scotch tape and a magic box. J. Nelson, *Diamond International*, November–December 1995, pp. 47, 48, 51, 52, 54.

This paper describes a visionary new method of detecting fracture-filled diamonds, by a type of stereo-radiography. The author developed the technique after observing that the detection of fillings by microscopic methods (specifically, by color-flash effects):

1. May not always be reliable (e.g., he describes a 2.14 ct filled diamond that exhibited only an extremely faint flash).
2. Is time-consuming, as each stone must be examined individually.
3. Requires a degree of expertise that many in the trade lack.

The basic principle behind the new technique is that the glass used in fracture filling (presumably because of its lead or other heavy-metal component) is less transparent (more opaque) to X-rays than its lower-density diamond host. As a result, the filling will be visible on X-ray film after irradiation. This is analogous to medical X-rays, where relatively dense bone, for example, is easily visible on the film, but the (lower density) fleshy parts of the human body are more transparent to the X-rays. The instrument required for this technique consists of three parts:

1. An open box-like compartment (the "magic box" of the title), which contains a moveable (especially tiltable) stone holder that uses "Scotch Tape" (also in the original title) to keep the diamonds in place during analysis.
2. An X-ray generator.
3. A viewer/scanner, which features a traversing stereoscopic microscope that has been modified to enable examination of both the X-radiographs and the corresponding stones in the same holder.

The instrument is currently used at the Asian Institute of Gemmology in Bangkok, Thailand, to scan batches of up to 300 loose stones (0.01–0.15 ct) for the presence of fillings.

Because it can simultaneously screen large numbers of stones (some of which may be filled and possibly flash-free), this instrument is a most valuable addition to gemological testing, especially for laboratories that process large numbers of loose diamonds. However, it is relatively expensive and complicated, it cannot screen mounted stones, and some jurisdictions may require special licensing because of potential radiation hazards. *AAL*

JEWELRY HISTORY

Alma Pihl's designs for Fabergé. V. Swift, *The Magazine Antiques*, Vol. 149, No. 1, January 1996, pp. 176–181.

Sumptuous photographs of Fabergé jewelry and *objets de vertu* pair with fascinating text in this piece by the former head of Christie's objects of vertu department. Two record books of master jeweler Albert Holmström, which were rediscovered by A. Kenneth Snowman, shed considerable light on the inner workings of the Fabergé workshop. These records reveal that Alma Theresia Pihl, the daughter of Finnish Fabergé workmaster Knut Oskar Pihl and Fanny Florentina Holmström (the sister of Albert Holmström), was more actively involved in the design of important pieces than was previously believed. In a move unusual for her time, Alma continued to work after her marriage in 1912 and became a respected designer in the famous workshop.

Alma Pihl was remarkable for many reasons, but three stand out. First, Fabergé so liked her designs that they adopted them even though she had just finished her apprenticeship. Second, unlike typical House of Fabergé designs, which were generally based on reinterpretations of historic styles, hers were innovative, taken from everyday life. Third, although ice was rarely a subject in the medium of jewelry, many of Pihl's most noteworthy designs were based on the theme of ice and snow. One is the Ice Egg, made for Dr. Emanuel Nobel. The Ice Egg was rediscovered in 1994 after being lost for many years. Deceptively simple, the design is an amazing example of the enameler's art. Another well-known Pihl design is the Mosaic Egg, which Czar Nicholas II presented to Czarina Alexandra Feodorovna on Easter 1914.

Unfortunately, Alma Pihl's career was cut short by the Russian Revolution of 1917. She escaped to Finland, where she stayed until her death in 1976. Her legacy lives on in the wonderful jeweled objects she designed. *JEC*

JEWELRY RETAILING

Estimating estimates: A bidder's guide. A. Walker, *Celator*, Vol. 9, No. 5, May 1995, pp. 36–40.

Although this article is in a coin-collecting magazine, the principles in it are probably useful for anyone bidding at auction. Those principles include:

- Avoid fractional, "cute" bids (e.g., $648 instead of $650).
- Avoid unreasonably low bids; these mark you either as an idiot or as someone only seeking market information with no real interest in buying.
- Avoid "system bidding," that is, bidding a percentage of the estimated price on multiple lots in the same auction. (Your only reward probably will be over-valued goods.)

The author explains how to make "sensible" bids, even when starting estimates are unrealistically low or absent altogether. This method consists of determining whether you want an item and then comparison shopping to estimate its value. Using this method, you decide reasonable starting and final bids. The author recommends using this method even if there are estimates. The estimates can then be compared with your bidding range.

If there is an item that you really want and you cannot attend the auction, you may opt to have a trusted dealer—who is attending—bid for you. This option is often preferable to bidding by mail, especially if your top bid is significantly higher than the estimate and if you are not well known to the auction house. *MLJ*

Gold Jewelry Sales Rise 5.1% in 3rd Quarter of 1995. M. K. Golay, *National Jeweler*, February 1, 1996, p. 28.

Third-quarter 1995 gold jewelry dollar sales increased 5.1%, and unit volume increased 4.7%, over the same period in 1994, according to the World Gold Council. This marks the 16th consecutive quarter of increased sales for gold jewelry. Year-to-date gold jewelry retail sales topped $6 billion, an increase of 5.9%. Unit volume for the nine-month period grew 7.7%. Discount stores remained the fastest growing retail outlets, with a 15.8% jump in dollar sales posted year-to-date over the same period in 1994.

Chain jewelry stores averaged a 4.9% dollar-sales increase as compared to the same period in 1994. Department stores (20.3% of total gold jewelry dollar sales) posted a 5.7% increase in dollar sales for the period, while catalog showrooms showed a 0.7% increase. Neckchains performed well below the category average, with a 3.2% increase in dollar sales year-to-date. Earrings and charms led all classifications, with a 13.9% increase in dollar sales over the prior year. A 5.5% increase in dollar sales was recorded for wedding rings, with a 6.2% increase recorded for bracelets. *MD*

Sotheby's and Christie's enjoy significant growth in worldwide jewellery auction sales. N. Packer, *Retail Jeweller*, August 10, 1995, p. 5.

Sotheby's and Christie's both experienced a significant boost in jewelry sales as part of a general growth in turnover during 1994–95. Christie's reported that jewelry sales were up 28%, due to strong buying from Saudi Arabia and Southeast Asia, as well as the establishment of regular Christie's Western jewelry and jadeite sales in Hong Kong and Singapore.

Meanwhile, the first half of 1995 was exceptional for Sotheby's, with worldwide jewelry sales increasing 40% to $122.2 million. Sotheby's retained its position as num-