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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 Bulfontein 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.

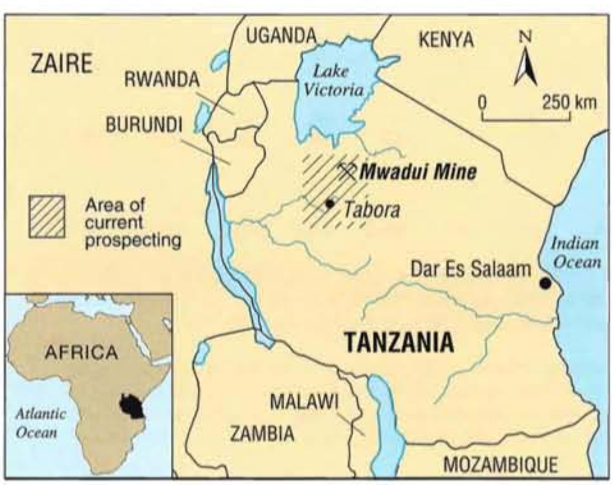

Figure 3. One of the most important diamonds to emerge from Mwadui, the 54 ct Williamson Pink diamond, was found in 1947 and subsequently given to then Princess Elizabeth (now Elizabeth II) of England as a wedding gift. It was cut into a flawless 23.60 ct light pink round brilliant and mounted as the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

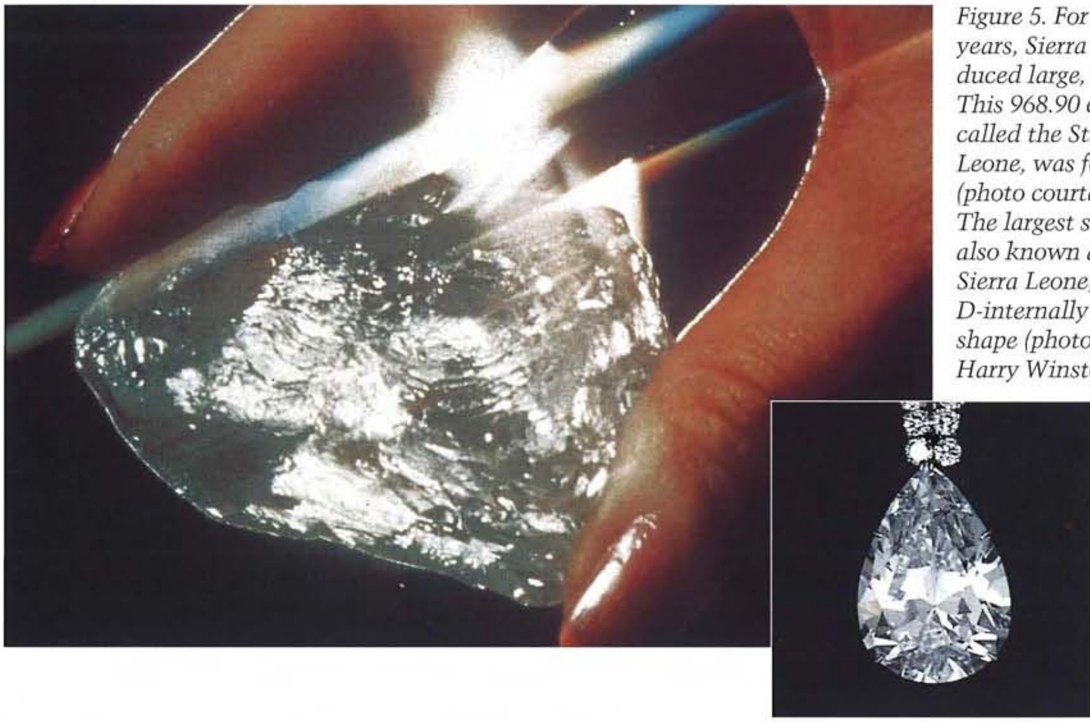

Figure 5. For more than 50 years, Sierra Leone has produced large, fine diamonds. This 968.90 ct piece of rough, called the Star of Sierra Leone, was found in 1972 (photo courtesy of De Beers). The largest stone cut from it, also known as the Star of Sierra Leone, was a 53.96 ct D-internally flawless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

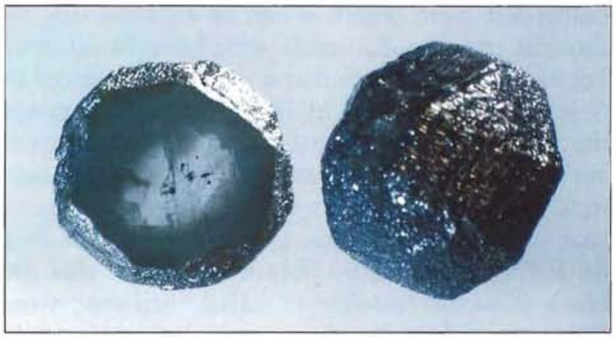

Figure 6. Coated diamonds—stones with green or rough skins over transparent interiors—are common in Sierra Leone and the Mbuji-Mayi region of Zaire. A window has been cut on one of these approximately 5-mm-diameter diamonds to show the color and clarity of the interior. Photo courtesy of Dearn Lee, Ashton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

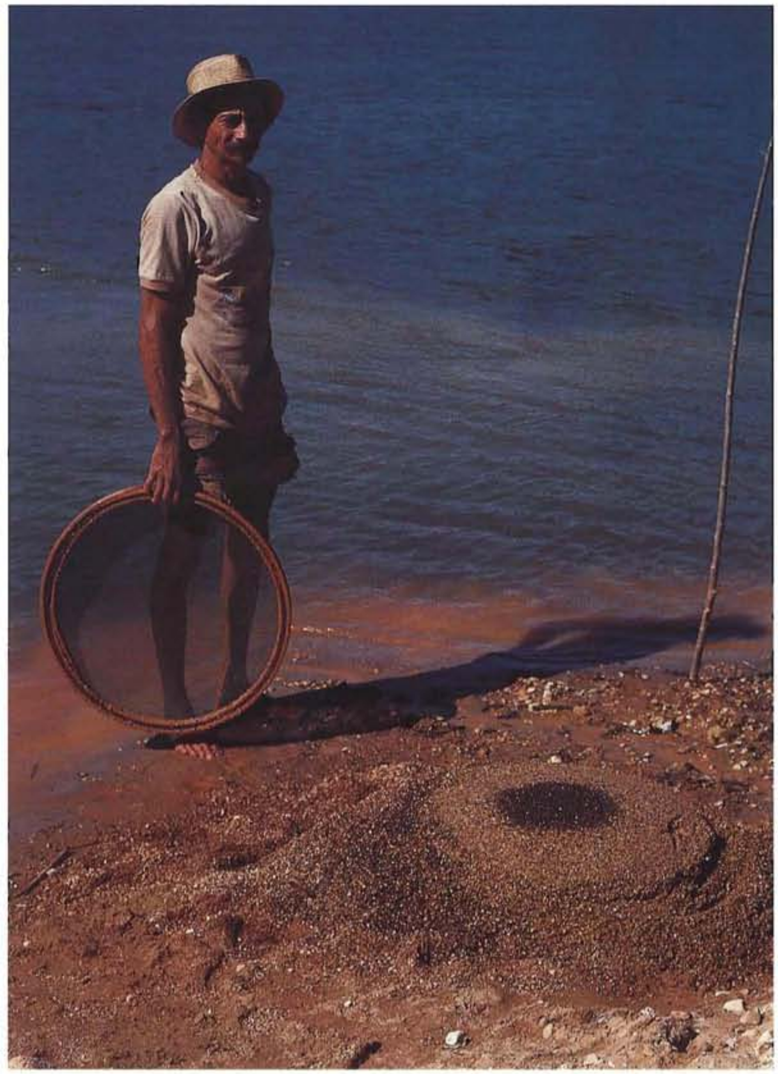

Figure 9. Simple hand gravitator sieves are still used in many parts of Africa to look for diamonds. Note the "dark eye" of heavy minerals in the center of the gravels. Photo by A. J. A. Janse.

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-