A History of Diamond Sources In Africa: Part II

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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.

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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 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).

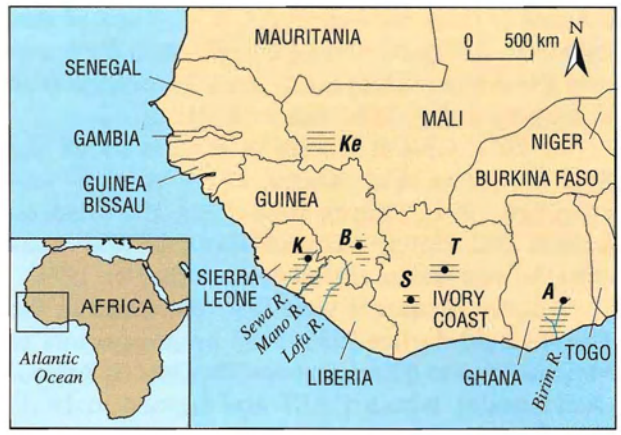


Figure 4. Numerous diamond deposits have been found throughout West Africa. The major deposits, as indicated here by stripes, are: A—Akwatia/Birim alluvials, Ghana; B—Banankoro alluvials and pipes, Guinea; K—Koidu pipes and dikes, Sierra Leone; Ke—Kéniéba alluvials and pipes, Mali; S—Séguéla alluvials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

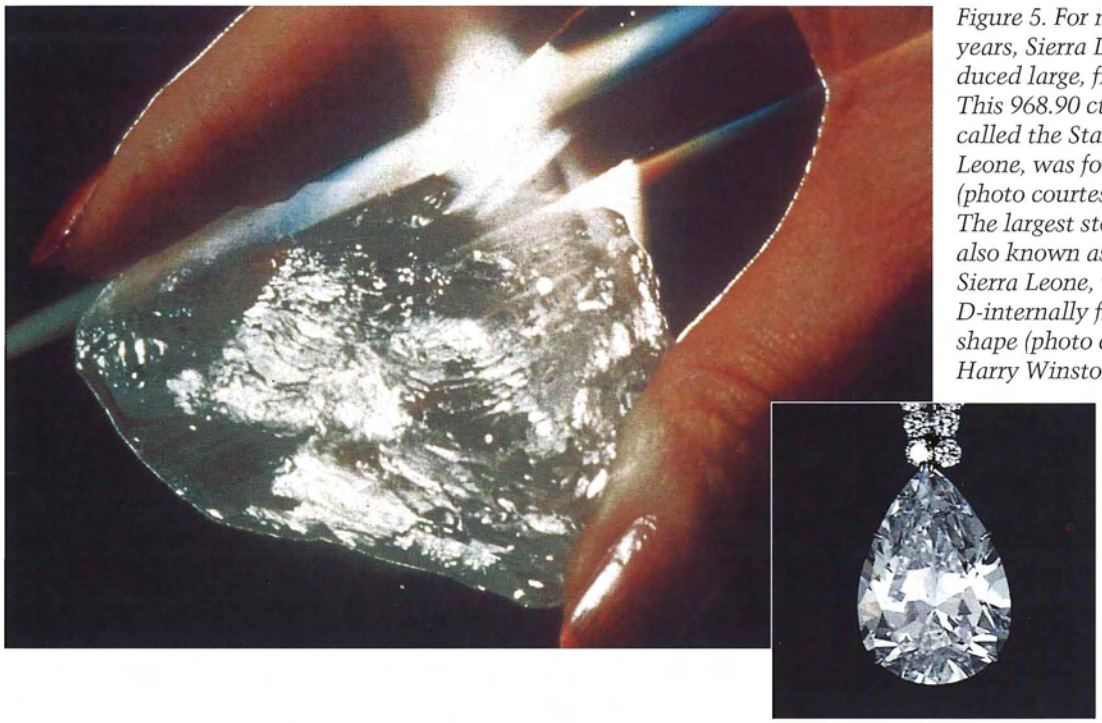


Figure 5. For more than 50 years, Sierra Leone has produced large, fine diamonds. This 968.90 ct piece of rough, called the Star of Sierra Leone, was found in 1972 (photo courtesy of De Beers). The largest stone cut from it, also known as the Star of Sierra Leone, was a 53.96 ct D-internally flawless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

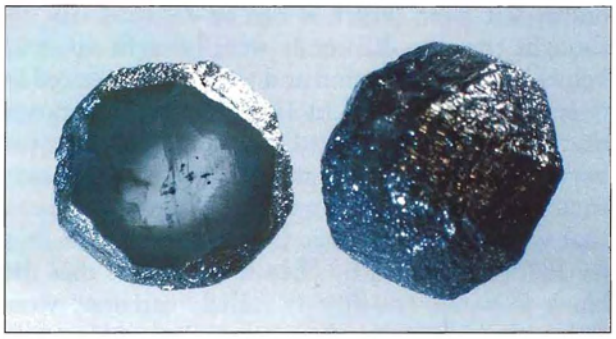


Figure 6. Coated diamonds—stones with green or rough skins over transparent interiors—are common in Sierra Leone and the Mbuji-Mayi region of Zaire. A window has been cut on one of these approximately 5-mm-diameter diamonds to show the color and clarity of the interior. Photo courtesy of Dearn Lee, Ashton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

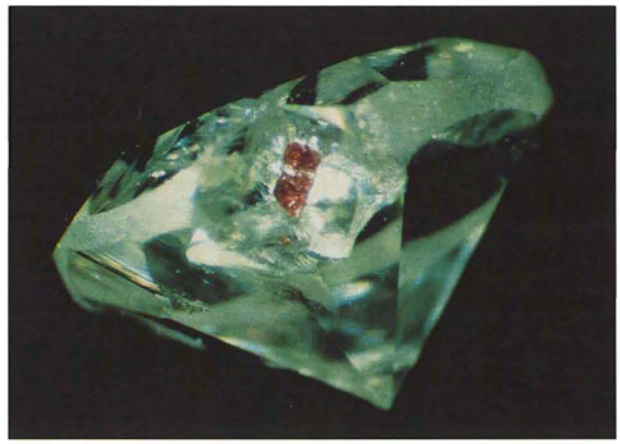


Figure 7. Garnet is an important diamond indicator mineral, having crystallized in a similar high pressure/moderate temperature environment in the mantle. The garnet shown here is included in a 2 ct diamond. Photo courtesy of Craig Smith; from the John J. Gurney collection.

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

Figure 8. Economic kimberlites are found only on those parts of cratons known as archons. This map of Africa shows the distribution of cratons (outlined in green) and archons (outlined in red). Solid red dots and red letters are pipes and dikes, green striped areas and green letters are alluvial deposits (note that some areas contain both green stripes and red dots, and the red-striped area marks the beach and off-shore deposits in Namibia and Namaqualand). Key to large, open green and red letters: B—Bangweulo archon; CA—Central African craton; G—Gabon archon; KA—Kalahari archon; LK—Lunda-Kasai archon; M—Man archon; R—Reguibat archon; SA—South African craton; T—Tanzania archon; WA—West African craton. Key to solid red and green letters: A—Akwatia/Birim alluvials; B—Banankoro alluvials and pipes; Bf—Buffels River alluvials; Cb—Carnot/Berbérati alluvials; Cu—Cuango alluvials and pipes; Do—Dokolwayo pipe; F—Finsch pipe; G—Gope pipe; J—Jwaneng pipe; Ja—Jagersfontein pipe; K—Koidu pipes and dikes; Kb—Kimberley pipes (5); Ko—Koffiefontein pipe; L—Letlhakane pipe; Le—Letseng pipe; Li—Lichtenburg alluvials; Lo—Lower Orange River alluvials; Lu—Lunda pipes and alluvials; M—Mitzic kimberlites; Mb—Mbuji-Mayi pipes, eluvials, and alluvials; Mo—Mouka Ouadda alluvials; Mw—Mwadui pipe; O—Orapa pipe; P—Premier pipe; R—River Ranch pipe; Rg—Reggane; S—Séguéla alluvials and dikes; St—star fissure; T—Tortiya alluvials; Ts—Tshikapa alluvials; V—Venetia pipe; Vo—Vaal/Orange Rivers alluvials; Ye—Yengema alluvials.

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.

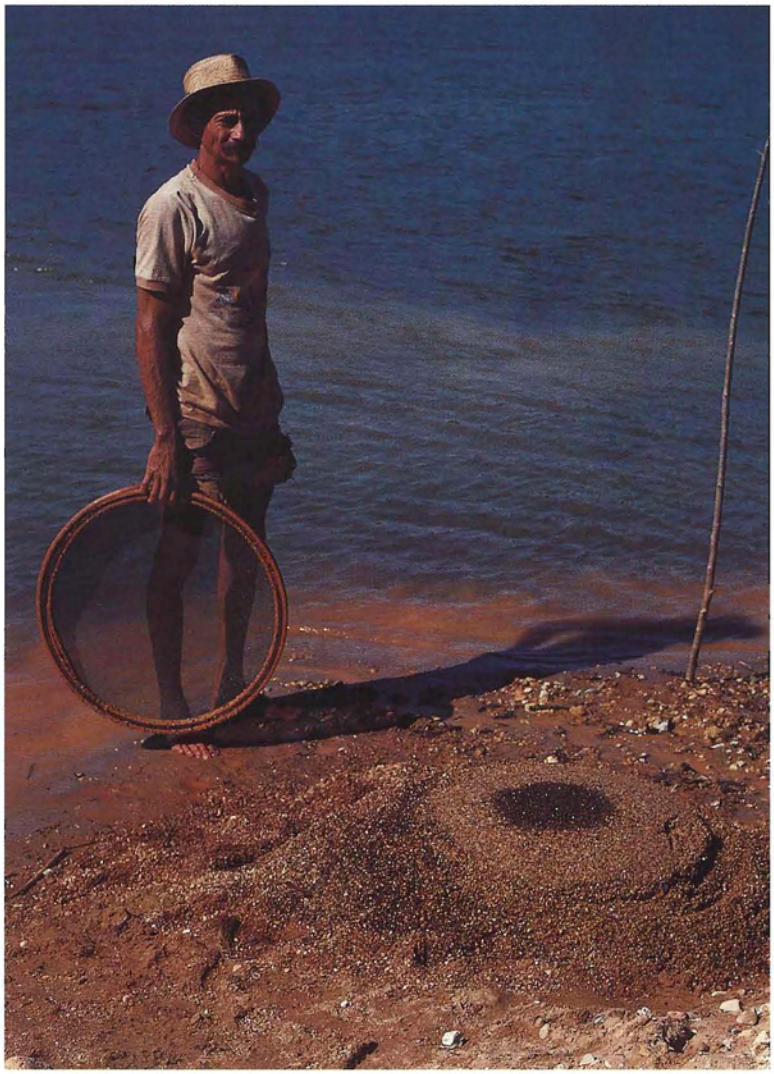


Figure 9. Simple hand gravitator sieves are still used in many parts of Africa to look for diamonds. Note the "dark eye" of heavy minerals in the center of the gravels. Photo by A. J. A. Janse.

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-

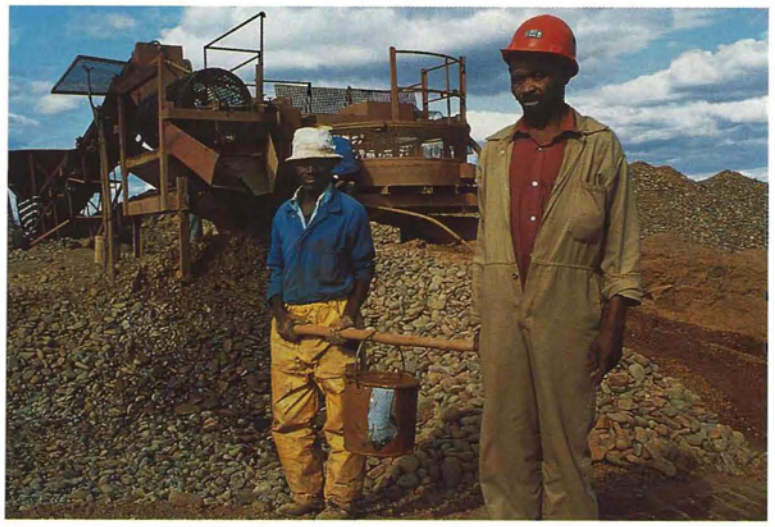


Figure 10. Simple trommels and jigs are still used today to process the ore at small aluvial mines such as this one in South Africa. Photo courtesy of Robert E. Kane.

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-

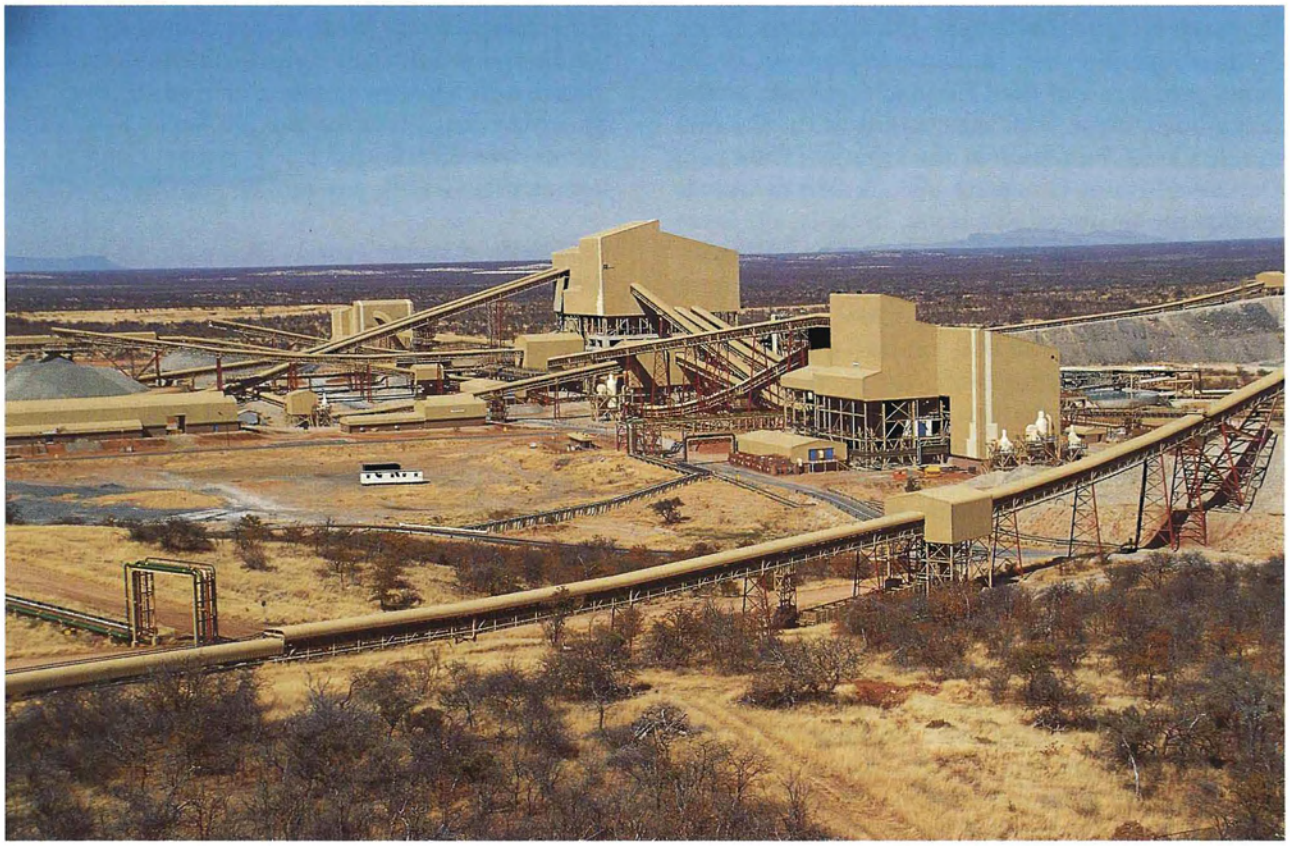
lite pipes—the Bultfontein, Dutoitspan, and Wesselton mines in the Kimberley area, and the Jagersfontein and Koffiefontein mines in the Orange Free State—and leased the production rights. So, from 1888 to 1900, De Beers produced nearly all the world's diamonds.

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 alluvial 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-bearing gravels. Photo by Manfred Marx.

more stones (17% of world total), but these represented 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 alluvial deposits. Production from Angola is likely to increase greatly; in the next decade, it may overtake 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 million 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 century or perhaps even in this decade. Given the limited information presently available, no prediction as to the scope and success ratio of these investigations 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.*

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