GLOBAL ROUGH DIAMOND PRODUCTION SINCE 1870

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Data for global annual rough diamond production (both carat weight and value) from 1870 to 2005 were compiled and analyzed. Production statistics over this period are given for 27 diamond-producing countries, 24 major diamond mines, and eight advanced projects. Historically, global production has seen numerous rises—as new mines were opened—and falls—as wars, political upheavals, and financial crises interfered with mining or drove down demand. Production from Africa (first South Africa, later joined by South-West Africa [Namibia], then West Africa and the Congo) was dominant until the middle of the 20th century. Not until the 1960s did production from non-African sources (first the Soviet Union, then Australia, and now Canada) become important. Distinctions between carat weight and value affect relative importance to a significant degree. The total global production from antiquity to 2005 is estimated to be 4.5 billion carats valued at US$300 billion, with an average value per carat of $67. For the 1870–2005 period, South Africa ranks first in value and fourth in carat weight, mainly due to its long history of production. Botswana ranks second in value and fifth in carat weight, although its history dates only from 1970. Global production for 2001–2005 is approximately 840 million carats with a total value of $55 billion, for an average value per carat of $65. For this period, USSR/Russia ranks first in weight and second in value, but Botswana is first in value and third in weight, just behind Australia.

Although diamonds from alluvial deposits have been known since antiquity (figure 1), production from primary deposits (kimberlites and, since 1985, lamproites) began only in the 1870s. Over the last 135 years or so, annual production has risen from ~1 million carats (Mct) in 1872 to 176.7 Mct in 2005, though this increase has been anything but smooth. Production has followed the ups and downs of the world economy, with sudden increases brought about by new discoveries and just as precipitous drops caused by political upheavals and similar events. An awareness of the production figures for the modern history of diamond mining not only helps us understand the impact of both political developments and geologic factors over time, but it also helps the exploration geologist, diamantaire, and jeweler alike plan for future additions and disruptions to the supply chain.

This article represents an expanded version of the data and illustrations previously published in Janse (2006a,b), and is a companion piece to Boyajian (1988) and Shor (2005). Assembling the data for annual global rough diamond production (gem, near-gem, and industrial) was a difficult task, because the numbers for several countries may vary more than 10% between different publications. To achieve as much consistency as possible, production figures were taken from sources that are believed to be reliable and, for the most part, that were continuously published in the United States. For the period 1870–1934, these included *The Mineral Industry* (from the Scientific Publishing Co.) and *Mineral Resources of the United States* (compiled by the U.S. Bureau of Mines). For the period 1934–2005, data were taken from *Minerals Yearbook* (also by the U.S. Bureau of Mines). Wagner (1914) was consulted for early South African production. For 2004 and 2005,

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Figure 1. Diamonds have been valued since antiquity, but only since the late 19th century have they become an important element of the world economy. They were first known in India, and then Indonesia and Brazil, but it was the 1867 discovery in South Africa that would launch the modern diamond market. Though India is no longer an important producer, it remains an essential link in the diamond supply chain through its polishing and trading centers. Shown here is an Indian diamond and emerald necklace from the early 19th century. Courtesy of Christie's Images.

Kimberley Process Certification Scheme production reports were also used. A cut-off date of December 31, 2005, was selected because that is the most recent year for which robust data are available. Although 2006 production figures for some mines have been released as of the date of publication of this article (mid-2007), incorporating them would distort the overall picture, as Kimberley Process data for 2006 have not yet been released. Figures for production data are necessarily best estimates compiled from the most reliable sources, but the trend and amplitude of changes in production and cumulative totals are considered by the author to be as close to reality as possible.

In the first part of this article, data are presented in a series of graphs illustrating: (1) annual production by country (divided into 10 groups: eight major source countries, one region [West Africa, including Guinea, Sierra Leone, Liberia, Ivory Coast, and Ghana], and one group representing other and minor producers [including Lesotho, Swaziland, Rhodesia/Zimbabwe, Central African Republic, Tanzania, Brazil, Venezuela, Guyana, China, United States, India, and Indonesia]); (2) percentage of total by country; (3) percentage by type of deposit; and (4) percentage by category of diamond. The first three categories are further divided according to carat weight and U.S. dollar value of production.

In the second part of the article, data are given regarding the ownership, location, size, and other aspects of the 24 historically most important diamond mines and eight major advanced diamond projects currently in development. In the third part, data are provided for historic and contemporary production for the 27 most significant diamond-producing countries through 2005.

ANNUAL PRODUCTION BY COUNTRY

By Carat Weight. Historically, production has been as much a function of changes in demand as it has been of the introduction or closure of mining operations.

Figure 2 shows the annual production (by weight) of rough diamonds for the 10 most important diamond-producing regions from 1870 to 2005; more detail is provided below. For the most part, the regions are discussed and plotted chronologically by date of earliest production; South Africa is introduced first as it is historically the most important.

South Africa. After mining of diamonds began in 1869, South African production rose rapidly to 1 Mct in 1872 and thereafter to 5 Mct in 1907, in 1909, and in 1913, with a few peaks and dips during this period. A dip in 1900 was due to the Boer War and the Siege of Kimberley. A peak in 1907 in response to rapidly growing U.S. demand was not reached again until 1966; it was followed by a sharp dip in 1908 due to a financial crisis in the U.S., and then production went back up again the next year. A steep drop in 1914 and 1915 was caused by World War I (WWI), but then production rose quickly and stayed at a moderate level from 1916 to 1920. In 1921–22, production fell again due to a general depression in the economy (the aftereffects of WWI and the 1918–19 flu pandemic) as well as a sudden influx of jewelry on the market due to the combination of Russian émigrés from the Bolshevik revolution having to sell their valuables to survive just as the new Soviet government was selling confiscated jewels (Janse, 1996).

Beginning in 1923, South African production rose again in response to the discovery of the Lichtenburg alluvial field and the Namaqualand beach deposits along the Atlantic coast, but it was extremely low from 1932 to 1944 as a result of the Great Depression of the 1930s and the impact of World War II. The Premier mine closed in 1932, and the Kimberley mines were closed for several years during this period. In 1948, the Premier and Kimberley mines reopened, causing production to rise gradually over the next two decades. There was a jump in 1968 when the Finsch mine came into full operation, after which production continued to rise gradually to 10 Mct in 1986. The global stock market crash in October 1987 precipitated a slight decline in production, but the upward trend resumed and gained momentum in 1992 when the Venetia mine came on stream. Production has climbed steadily since then to 15.56 Mct in 2005.

South-West Africa (SWA)/Namibia. Production began in 1909 and quickly reached 1 Mct annually during 1912–13 under German administration; it then fell to virtually zero in 1914–15 because of WWI. Production resumed after the war but did not reach the 1 Mct mark again until 1962. It reached 2 Mct in the late 1960s and again in the 1970s, but then dropped to 0.9 Mct in the late 1980s. Production increased to 1.5 million in the 1990s, and in 2005 it amounted to 1.87 Mct.

Congo/Zaire/Democratic Republic of the Congo (DRC). The 1932–80 period was the heyday (in terms of its share of world production) for this region. Congo production began in 1917 and reached 18 Mct annually in 1961. After independence in 1960, it eventually declined to less than half that by 1981; however, it rose to 26 Mct in 1998. The fall of then-President Mobuto Sese Seko and the ensuing unrest led to a brief decline. Conditions stabilized in 2001, as Joseph Kabila took over from his assassinated father, and diamond production rose again to around 30 Mct in 2005.

Angola. Production began in 1921, but not until 1969 did it reach 2 Mct, where it stayed until 1974. From 1975 to 1995, production saw many ups and downs due to the country's protracted internal unrest. After conditions improved in 1995 and the Catoca mine came on stream in 1998, official annual production reached 3 Mct in 1999. Still, estimates by Cilliers and Dietrich (2000) indicate that, during the 1990s, "informal" production was much higher than the official figures, accounting for more than twice the official production in 1996 and 1997. Some sources estimate that the total of official production plus UNITA's smuggled production reached close to $1 billion in 1996 (Partnership Africa Canada, 2004a). It was also claimed that UNITA *alone* accounted for $1 billion (Partnership Africa Canada, 2005a). These disparate reports illustrate how difficult it is to estimate illicit or informal production. Where it exists to a significant degree, production figures—both official and unofficial—must be viewed with caution.

After the conflict eased in 2000, the government was able to assert greater control, and official production rose to its maximum level of 7.1 Mct. This was due to an increase in both licensed and unlicensed artisanal alluvial mining, and to expansion of Catoca, which is at present Angola's sole producing kimberlite pipe.

West Africa. West African production became significant in the early 1930s. It stayed around 2.5 Mct until 1954, then rose to its maximum level of 7.5 Mct in 1960. Civil disorder over a large part of the region and

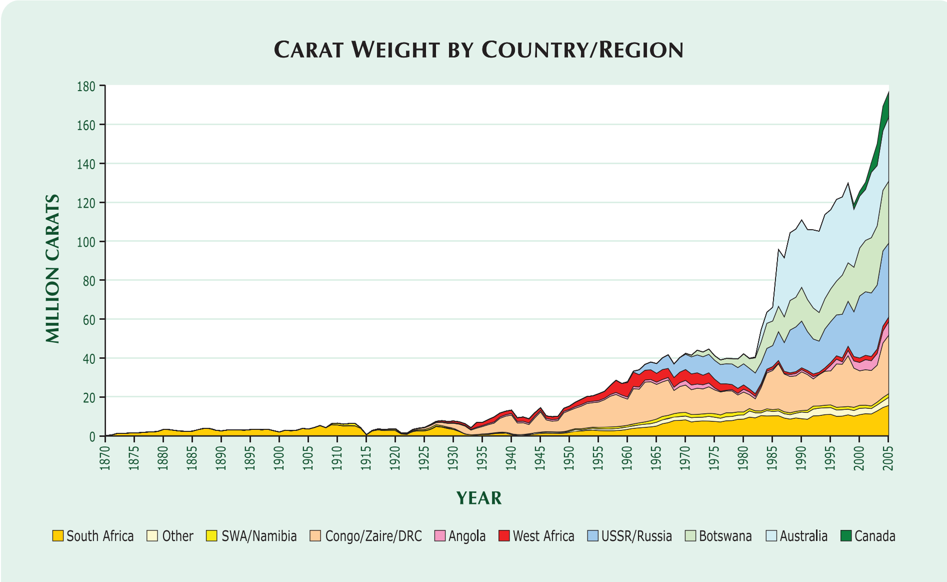


Figure 2. This chart shows global diamond production by carat weight from 1870 to 2005 for eight countries, one region in Africa, and all other producers ("Other"). South Africa's early dominance gave way to production from the Belgian Congo in the 1930s, which in turn was eclipsed by production from Russia, Botswana, and Australia.

an increase in illicit production brought the official level down during 1960–65. It reached a peak in 1972, after which it declined from 1984 to 1990. It rose again after 1997, amounting to 2.4 Mct in 2005.

Soviet Union/Russia. Soviet production commenced in 1960, and sources used to estimate the caratage mined indicate that it rose quickly to 7 Mct in 1967 and 10.3 Mct in 1977. It stayed around this level until 1985 and then rose to 24 Mct in 1990. Following the dissolution of the Soviet Union in 1991, there was a slight dip in 1993, and from then on a gradual increase to 23 Mct in 2002.

These were the *estimated* figures, however, as the actual numbers were considered state secrets during this period. It appears now that in fact the annual Russian diamond production by weight has been significantly underestimated for years, since production was only reported in *monetary* values. Based on the assumption that the overall value per carat was similar to that of South Africa and Botswana, Russia's annual production was estimated at around 20–23 Mct for the last 10 years. When Russia became the annual president for the Kimberley Process in 2005, Alrosa (Russia's major diamond mining company) released data at the end of 2004 that showed the US$1.68 billion value for 2003 was actually based on $51/ct (Janse, 2005) and not on the values of about $80/ct given in world diamond production figures reported by reputable sources (e.g., Government of Northwest Territories, 2001–2004; Even-Zohar, 2002). This raised the production for 2003 from the assumed 19 Mct to a staggering 33 Mct.

The lower value per carat was due to the fact that Russian mines recover diamonds down to 0.2 mm, which increases the grade and the cost, but lowers the value per carat. The production for 2004 was worth about $2.2 billion, with an average value of $56.74/ct, which equates to an annual production of 38.7 Mct for 2004 (Kimberley Process Certification Scheme, 2004). The value of production for 2005 was $2.53 billion, with an average value per carat of $66.61 (Kimberley Process Certification Scheme, 2005). This translates to an annual production of 38 Mct for 2005. This higher value per carat may be due to the fact that new mines—the Nyurba open pit and the Aikhal and Internationalaya underground operations—have adopted a screen-size cut off of 1.5–2 mm, as is the custom for Western mining companies, which increases the average value per carat (screen size and its effects on grade and value are discussed in more detail in the Major Diamond Mines/Current Value section below).

Botswana. Production began in 1970 and rose to 2.5 Mct in 1972, when the Orapa mine reached full capacity. Orapa's expansion in 1979 and the opening of the Letlhakane mine brought the level up to 5 Mct in 1980; this doubled to 10 Mct in 1983 as the Jwaneng mine came on board, and doubled again by 1997, after further expansion of Orapa. It has climbed steadily since, to about 32 Mct in 2005.

Australia. Meaningful production commenced after a diamond-bearing lamproite was discovered near Lake Argyle in 1979 (Shigley et al., 2001). The first diamonds (0.5 Mct in 1982) came from alluvial deposits nearby; alluvial and surface mining produced 7 Mct in 1985. When mining of the AK1 pipe began in 1986, production soared to 29 Mct that first year, then rose gradually to a peak of 43.3 Mct in 1994. Annual production dropped sharply from 40.9 Mct in 1997 to 26.7 Mct in 2000 due to reconstruction of the open pit, which necessitated the removal of much barren ground. Production further declined to 26 Mct in 2001 with the mining of lower-grade ore, after which it rebounded to about 33 Mct in 2005. The open pit will be phased out by 2008, when underground mining will commence. (The Argyle underground mine is discussed further in the Advanced Diamond Projects section below.)

Canada. The latest entry is Canada, which began production in 1998 (Kjarsgaard and Levinson, 2002) and reached 5 Mct in 2002, all derived from the Ekati mine. With the opening of the Diavik mine in 2003, production rose to 11 Mct that year and then to the 2005 level of 12.8 Mct.

Other Producers. Individual production from the remaining producers has generally been less than 0.5% (by weight) of global annual production. The exceptions are the Central African Republic (0.22% by weight, 0.51% by value), which for many years has produced about 400,000 carats valued at about $60 million annually, and Lesotho (0.03% by weight, 0.55% by value), which started mining in 2004 and in 2005 produced 52,000 carats worth $64.3 million. Notably, Lesotho has produced some large diamonds valued at over $1,240/ct (Kimberley Process Certification Scheme, 2005). Its production will tend to increase as the country's two diamond mines (Letseng and Liqhobong) are developed further. Production in Zimbabwe (0.31%) commenced in 2004 and is planned at 250,000 carats (worth $36 million) annually, though the current political situation makes this uncertain. Tanzania (0.13% by weight, 0.22% by value) produced 220,000 carats worth $25.5 million in 2005 and will probably stay at this level. Estimates for annual Brazilian production (including informal production) have been up to 1 Mct in the past, according to U.S. sources, but Kimberley Process data for 2005 put it at 300,000 carats worth $21.85 million. Including Guyana and Venezuela, South America currently accounts for 700,000 carats worth $57 million, which is only 0.4% by weight and 0.5% by value of global production. Similarly, annual production for China was estimated at 1.1–1.2 Mct by U.S. sources, but was only 71,764 carats worth $1 million for 2005 by Kimberley Process data. Other minor producers in 2005 were India (60,000 carats worth $98 million) and Indonesia (17,557 carats worth $5 million).

Worldwide. Global production for 2005 was 176.7 Mct, a staggering amount compared to earlier years: 1.9 Mct in 1900; 4.2 Mct in 1925; 15.2 Mct in 1950; 41.6 Mct in 1975; and 126 Mct in 2000 (though the number for 2000 represented a dip because of the decrease in Australian production from 1997 to 2000; see above).

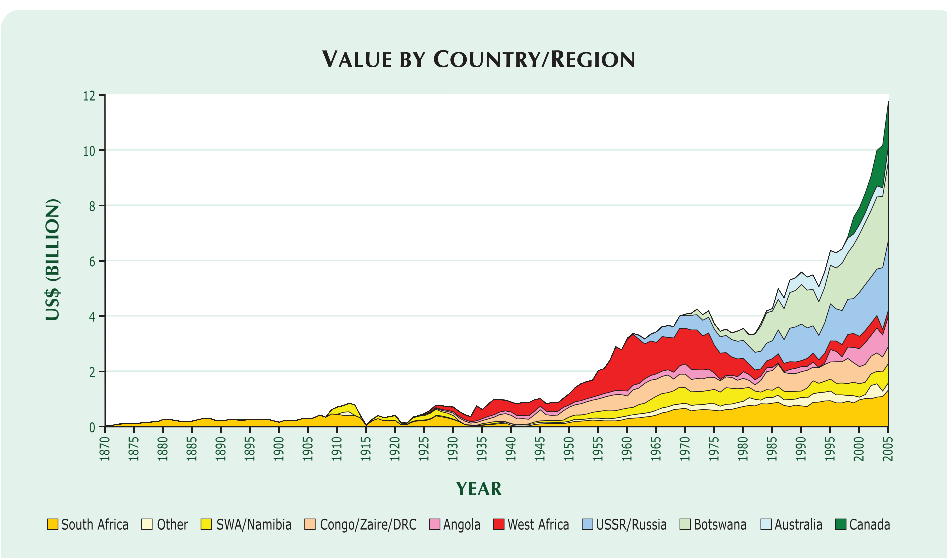


Figure 3. This chart shows production by (year 2000) U.S. dollar value for the same regions as in figure 2. Here, Congo/Zaire/DRC production for the most part is much less important than that of the higher-value alluvial diamonds from West Africa, and Australia's production is no longer as significant as that from Russia and Botswana.

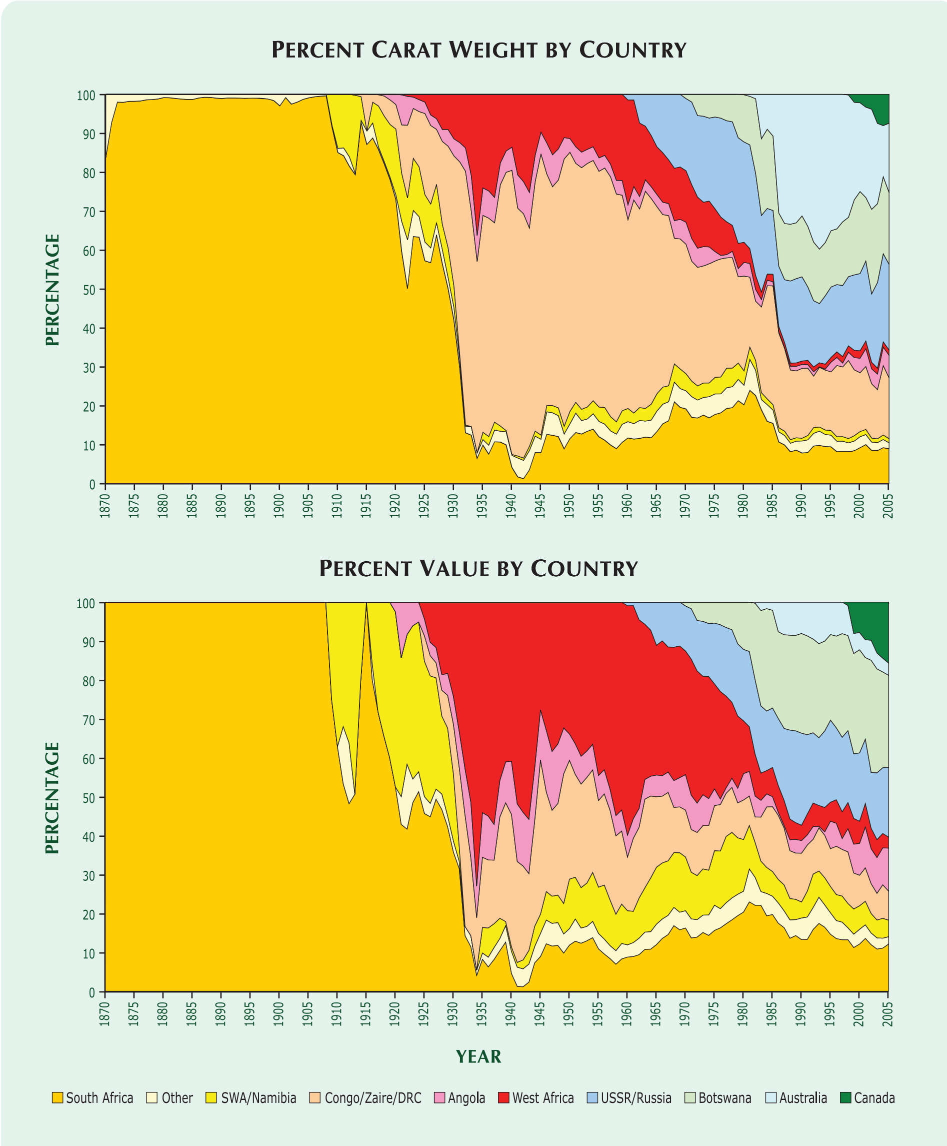


Figure 4. These charts compare the data in figures 2 and 3 as percentages of world production by country. The early dominance of Congo/Zaire/DRC production is clear when considered by carat weight (top), again giving way to Australia, Russia, and Botswana. Considered by dollar value (bottom), however, the alluvial production from West Africa is dominant from 1935 to the early '70s, while the lower value of Australia's production greatly reduces its impact.

By Value. The graph for annual values of production, based on year 2000 U.S. dollars (figure 3), shows quite different features compared to the graph for carat weight. The significant value of the South-West Africa production from 1910 to 1913 is quite distinct. In contrast, the band for Congo/Zaire/DRC from 1930 to 2005 is narrower due to the low value per carat. Angola shows an increase during the last decade, but the thickness of the band for West Africa from 1935 to 1975 is quite remarkable due to the high value of the diamonds from Sierra Leone and Guinea. The greatest contrast is shown by Australia: The band from 1985 to 2000 for value is very thin compared to that for carat weight (again, see figure 2), due to the low average value and the large quantities of diamonds produced.

RELATIVE PERCENTAGES FOR EACH COUNTRY BY WEIGHT AND VALUE

The annual production data have also been plotted as percentages of total production by weight and value for the same groups as in figures 2 and 3. This gives a better understanding of the relative significance of the producing countries. Figure 4 (top) shows the dominance of South African production by weight from 1870 to about 1930. A small shift occurred in 1909, when production from the coastal deposits in South-West Africa commenced, but a dramatic shift occurred after 1930, when most diamonds came from alluvial operations in the Belgian Congo and West Africa. The proportion from those two regions had started to decline by 1970, after production first from the USSR and then from Botswana entered the market, with another big shift occurring when Australia's Argyle mine came on stream in 1986.

The percentages for value (figure 4, bottom) also show the dramatic shift after 1930, but here we see the greater impact of the higher value per carat brought by the rough from South-West Africa and especially West Africa. The shift after 1985, when Australian production commenced, is less pronounced, because the value of Australian rough is low, especially as compared to the diamonds from Botswana.

RELATIVE PERCENTAGES BY TYPE OF DEPOSIT

The relative proportions of diamonds produced from pipes (primary kimberlite or lamproite deposits), alluvials (secondary deposits formed by erosion and subsequent river transport), or beach (littoral deposits, discharged from river mouths into the ocean) have varied greatly over time. The two graphs in figure 5 show the percentages of annual production by weight and value represented by these three types of deposits.

By Weight. Although the earliest diamonds to enter the marketplace came from alluvial deposits in India (from antiquity to the mid-18th century) and Brazil (from the 1720s onward), truly commercial quantities did not become available until the discovery of diamonds related to kimberlite pipes in South Africa starting in the late 1860s (see, e.g., Janse, 1995). Diamond production rose from tens of thousands of carats in the late 1860s to more than one million carats in 1872, almost all produced from the pipes at Kimberley (figure 6). During this period, only minor production came from alluvial deposits in Brazil and South Africa. From 1872 to 1909, pipe production reigned supreme.

For the next 50 years, 1910–60, the relative proportions of diamonds produced from primary versus alluvial and beach deposits shifted dramatically. Large beach and alluvial deposits were discovered, first along the coast of South-West Africa and later in the Belgian Congo, Angola (figure 7), West Africa, and South Africa (along the coast of Namaqualand and inland near Lichtenburg). By 1935, pipe production had dropped to less than 4% of the total versus 95% alluvial production (the remainder representing beach production). The sudden rise in alluvial production and dip in beach production (from German-occupied South-West Africa) in 1915 are anomalies due to WWI. Otherwise, production from beach deposits is significant from 1909 to 1925 and reached peaks of 12% in 1912 under German administration (SWA), and 16% in 1920 under the new administra-

Figure 5. Shown here are the trends in global diamond production by type of deposit, as percentages of the total. In carat weight (left), pipe production from South Africa constituted the bulk of world production until alluvial deposits from West Africa and Central Africa (the Belgian Congo and Angola) came on stream in the 1930s. With the discovery of large primary deposits in Russia, Botswana, Australia, and (most recently) Canada, pipe production has made a comeback since the 1960s. The trends by value (right) are similar, although South-West Africa/Namibia's beach production (and its high-value diamonds) are more significant, and the dominance of pipe production since the 1970s is not as pronounced, in large part because of the low-value diamonds from Australia's Argyle deposit.

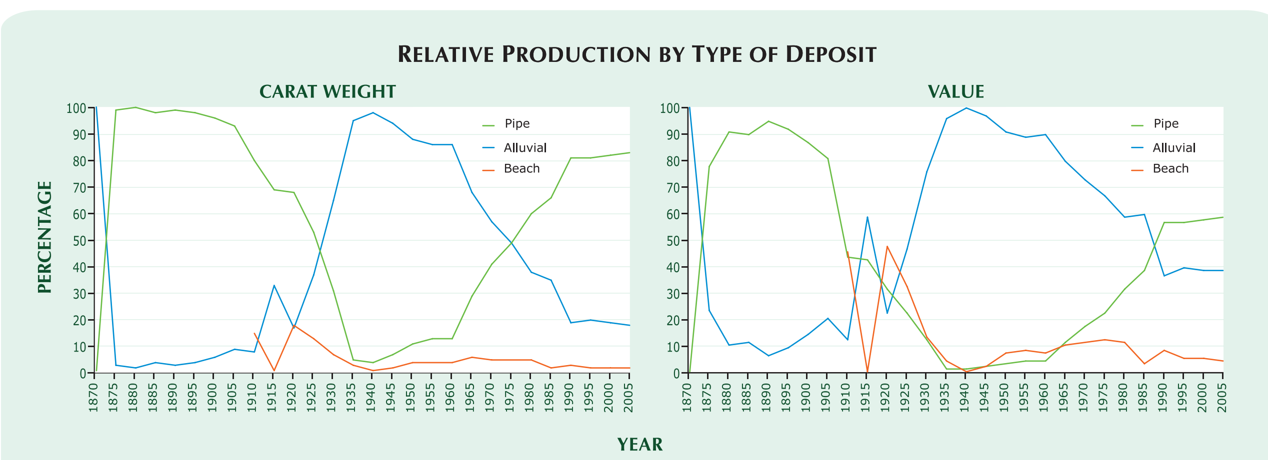


Figure 6. This 1872 photo shows the chaotic conditions that existed at the Kimberley pit in South Africa shortly after diamond mining there began in earnest. Annual world production by this point had already leaped from a few tens of thousands of carats to over a million. Photo © Bettmann/Corbis.

tion of the Consolidated Diamond Mines of South Africa, after which it declined in proportion to the rise in alluvial production.

Pipe production started to make a comeback in the 1960s, when modern methods of prospecting (stream sampling surveys for indicator minerals and airborne magnetic surveys) resulted in the discovery of large kimberlite pipes in South Africa (Finsch), Botswana (Orapa; figure 8), and Siberia (Mir and Udachnaya), which came on stream from the middle of the decade into the early 1970s. By 1990, with numerous additional discoveries, production of primary deposits represented 80% of the total, and this number has continued to creep upward since then. Although these discoveries reestablished the dominance of pipe production, they also began to shift the focus away from Africa. Before 1960, African countries accounted for nearly all the world's diamonds (again, see figure 4). In 1980, however, African pipe, alluvial, and beach deposits combined accounted for 70% of the total, with 25% from Siberia (virtually all pipe), and 5% from others (mainly alluvial).

Figure 7. The discovery of alluvial deposits elsewhere in Africa signaled a shift from pipe mining to alluvial mining that persisted until the middle of the 20th century. The rich alluvial deposits in Angola are worked by both large mechanized mining operations and small groups of artisanal diggers, such as these miners in Lunda-Norte Province in northwest Angola. Photo © 2007 Olivier Polet/Corbis.

Figure 8. Discovered in 1967 (and shown here in 2005), the Orapa mine in Botswana is one of the largest kimberlite deposits ever developed. Though later eclipsed in value by the Jwaneng mine (discovered in 1973), it remains a key element in Botswana's diamond industry. The discovery of large mines there and in Russia through modern prospecting methods helped reestablish the dominance of pipe production in the 1960s and 1970s. Photo by Robert Weldon.

The percentages shifted again when the Argyle AK1 lamproite pipe was discovered in 1979 and came on stream in 1986. Argyle is the world's largest single deposit in terms of production by weight, and at its peak in 1994 it yielded up to 40% of world production (though only 7% by value); that year, most of the remaining diamonds came from Russia (15%) and Africa (42%). Production from the Argyle pipe pushed global pipe production over 80%. Although Argyle's annual production had declined by 2000, it is likely that global pipe production will stay at this level due to recently discovered pipes in Canada, Russia, and Angola.

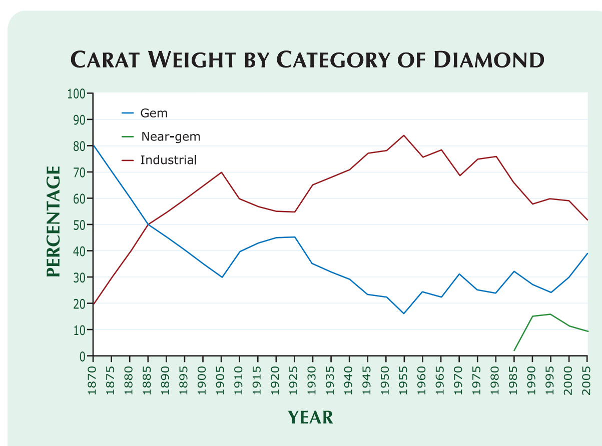
By Value. The annual production by value for each type of deposit shows a pattern similar to that for carat weight, except that the dominance of alluvial production from 1925 to 1980 is more pronounced. It clearly demonstrates the high value of beach deposits during their active years for the periods 1910 to 1930 and 1960 to 1990, though tapering off toward 2005. After 1980, the Argyle pipe is far less dominant because of the low value of its diamonds, while the high value of African alluvial production has retained its importance.

RELATIVE PERCENTAGES BY CATEGORY OF DIAMOND

The production data given thus far have included all qualities of diamond, gem and non-gem. Figure 9 shows the division into gem, industrial, and (over the last two decades) near-gem diamonds.

Before 1870, the percentage of gem-quality diamonds was high because all production was derived from alluvial deposits, and primitive mining methods were geared to recovering larger, good-looking stones. In the early days of pipe mining, recovery was still

Figure 9. The shifts in type of production (gem, industrial, and near-gem) in large part mirror the changes in technology and the types of deposits being mined. Early mining methods were not geared for the recovery of industrial diamonds, but this changed as modern pipe mining evolved. The peak in industrial production during the middle of the century reflects the large input of low-value diamonds from the Congo/Zaire. This began to fall as higher-value diamonds from Russia and other sources came on stream. Only since 1985, with the opening of the Argyle mine, is near-gem production indicated.



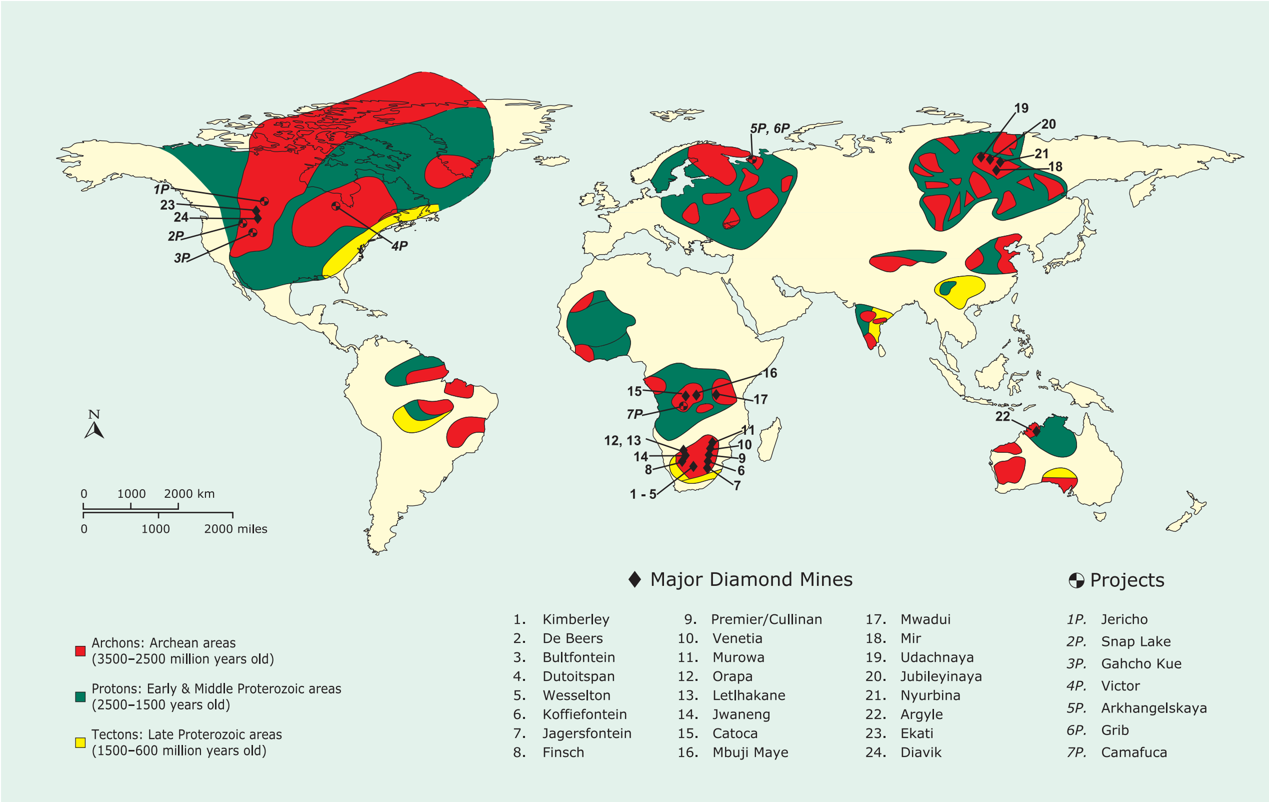


Figure 10. This map shows the tectonic location of 24 major diamond mines and seven advanced diamond projects. All major mines developed on kimberlite pipes are located within the boundaries of an archon, while those developed on lamproite pipes are located on a proton.

carried out by jigging, sieving, and hand sorting, and this tendency continued until about 1885. When recovery from the pipe mines became more mechanized, there was a progressive increase in the percentage of smaller stones and industrial diamonds, so that the proportion of gem-quality rough dropped gradually from 50% in 1885 to 30% in 1905. After this point, the gem percentage increased to 45% from 1910 to 1925 because of the emergence of the beach deposits, which yield mainly gem-quality stones. It declined again from 1925 to 1955 due to the large output from the Mbuji Maye mines in the Belgian Congo, which have a high percentage of small and industrial diamonds. From 1960 to 2000, gem diamonds varied between ~20% and ~30% of total production, but since then the proportion has increased because of the new Canadian mines, which have a high percentage of gem-quality diamonds, and the decreasing output from Argyle. The Argyle mine—and the corresponding development of a low-cost cutting industry in India to fashion small stones from rough that once would have been used for industrial purposes—is also responsible for the relatively new category, "near-gem" diamonds. Between 1985 and 1995, "near gems" represented as much as 17% of total production.

As would be expected, gem-quality diamonds are responsible for almost all production by value. Only in the last 20 years has the near-gem category had any significance. Between 1985 and 1995, it rose to represent as much as 10% of the total value of diamonds produced. With the declining production at Argyle, however, it had dropped to less than 4% by 2005.

THE MAJOR DIAMOND MINES

The world's 24 major diamond pipe mines (both historical and currently active) and seven (eight if Argyle's underground operation is included) advanced projects are plotted on figure 10, which shows the three tectonic crustal elements according to the Janse (1994) terminology—archons, protons, and tectons—which was developed from Clifford's Rule that kimberlites are restricted to cratons older than 1,500 million years (Clifford, 1966). Thus far, all major diamond mines developed on kimberlite pipes are located within the boundaries of an archon,

Figure 11. The Argyle diamond mine in northern Australia is the world's largest single producer of diamonds by weight, though the open pit is nearing the end of its active life. Argyle is also the only major mine situated on a lamproite pipe. Photo © Roger Garwood and Trish Ainslie/Corbis.

while those developed on lamproite pipes are located on a proton. Even though only one major diamond mine is underlain by a lamproite pipe (Argyle in Australia; figure 11), several small diamond mines on lamproite pipes and other occurrences of diamond-bearing lamproites (not shown on figure 10) are also located on protons and hence support this view. Figure 10 also shows that to date major diamond mines (other than Argyle) have clustered into three regions of the world: southern Africa, Siberia, and western Canada.

Data for ownership, location, size, annual production, ore reserves, value, and "life" for the 24 mines are compiled in table 1. Included is the status as of 2005 for 16 major active pipe mines. For comparison, historical data for seven important but inactive De Beers mines and the Mir open pit mine (closed in 1998; figure 12) are also provided. Table 1 comprises 15 columns, some of which are discussed in more detail below.

Name of Mine (Col. 1). Most of the mines are developed on a single pipe bearing the same name. In recent years, however, it has been found that an economically viable "mine" can be established by combining the volumes of several small pipes. Five such mining areas are included here: (1) Murowa, which draws ore from four small pipes; (2) Mbuji Maye, which includes production from the kimberlite pipes of Tshibua and its derived secondary deposits, as well as additional smaller pipes nearby; (3) Argyle, which for some periods (1983–1985; 1989–2002) drew up to 20% of its production from nearby alluvial deposits; and (4) Ekati and (5) Diavik, which draw ore from, respectively, five and two (increasing to four) pipes.

Majority Owner (Col. 2). Most of the older mines are (or were) owned outright by De Beers (in South Africa) or by De Beers in joint venture with local governments, such as Debswana (50% Botswana) and Mwadui (25% Tanzania). The Canadian mines are also jointly owned: Ekati (BHP 80%; Charles Fipke and Stewart Blusson, the original prospectors, 10% each) and Diavik (60% Rio Tinto, 40% Aber Resources; figure 13). Catoca is owned by a consortium of four entities: Endiama (an Angolan parastatal [government-owned] company) 32.8%, Alrosa 32.8%, Odebrecht (a Brazilian company) 16.4%, and Dau-monty Finance Corp. (a Lev Leviev company) 18%.

Size (Col. 4). It should be noted that in several cases only part of the total volume of a pipe is mined. For example, at Argyle the southern part—with a surface outcrop of 12 hectares—has been mined for most of its life, while only in the last two years has mining progressed to shallow northern parts of the pipe. The size given for Mbuji Maye is for Tshibua pipe 1 only.

TABLE 1. Historic and production data for 24 major diamond mines discovered since 1869.[a]

Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9	Col. 10	Col. 11	Col. 12	Col. 13	Col. 14	Col. 15
Name of mine	Majority owner	Country	Size (ha)[b]	Year of discovery	Year of opening	Annual production (kct/yr)[c]	Grade (cpht)[d]	Current value ($/ct)[d]	Current value ($/t)	Annual value (M$/yr)[e]	Total production (Mct)[f]	Total production (M$)[g]	Past life (yr)	Future life (yr)
Bultfontein[h]	De Beers	South Africa	9.7	1869	1901	874	54	75	40	66	24.5	1,838	105	Closed (2005)
Dutoitspan[h]	De Beers	South Africa	10.8	1869	1905	540	32	140	45	76	20	2,800	100	Closed (2005)
Jagersfontein[h]	De Beers	South Africa	10	1870	1902	363	12	200	24	73	9.5	1,900	60	Closed (1971)
Koffiefontein[h]	De Beers	South Africa	10.3	1870	1898	110	7	250	18	28	12	3,000	98	Closed (2005)
De Beers[h]	De Beers	South Africa	5.1	1871	1871	600	72	100	72	60	36.4	3,640	68	Closed (1960)
Kimberley[h]	De Beers	South Africa	3.7	1871	1871	500	200	80	160	40	32.7	2,900	44	Closed (1914)
Wesselton[h]	De Beers	South Africa	8.7	1891	1897	576	37	90	33	52	28.5	2,565	99	Closed (2005)
Premier/ Cullinan	De Beers	South Africa	32.2	1902	1903	1,250	40	75	30	94	146	10,950	103	5
Finsch	De Beers	South Africa	17.9	1961	1965	2,000	36	75	27	150	113	8,475	41	21
Venetia	De Beers	South Africa	12.7	1980	1991	6,800	122	90	110	612	68	6,120	15	11
Mwadui	De Beers	Tanzania	146	1940	1942	317	11	145	16	46	19	2,755	64	5
Orapa	Debswana	Botswana	118	1967	1971	16,000	95	50	48	800	222	11,100	35	23
Letlhakane	Debswana	Botswana	11.6	1968	1976	1,100	29	200	58	220	22	4,400	30	7
Jwaneng	Debswana	Botswana	45	1973	1982	15,600	140	110	154	1,716	238	26,180	24	23
Murowa	Rio Tinto	Zimbabwe	4	1997	2004	250	90	65	60	16	0.3	20	1	19
Mbuji Maye	MIBA	DRC	18.6	1946	1924	9,000	500	15	75	135	500	7,500	90	20
Catoca	consortium	Angola	66	1985	1997	6,000	45	75	34	450	23	1,725	9	20
Mir[i]	Alrosa	Russia	6.5	1955	1957	4,000	300	80	240	320	90	7,200	42	20[j]
Udachnaya	Alrosa	Russia	27	1955	1976	20,000	120	55	66	1,100	540	29,700	31	20[j]
Jubileynaya	Alrosa	Russia	50	1989	1997	10,000	56	45	25	450	50	2,250	9	20
Nyurba	Alrosa	Russia	nd	1998	2004	5,000	90	55	50	275	6	330	2	20
Argyle	Rio Tinto	Australia	46	1979	1985	30,476	310	13	40	396	700	9,100	21	10[j]
Ekati	BHP Billiton	Canada	11	1992	1998	6,000	100	140	140	840	32	4,480	7	13
Diavik	Rio Tinto	Canada	5	1994	2003	8,475	372	88	327	746	21	1,848	2	20

[a] *Sources: De Beers Consolidated Mines (1880–2005); Wagner (1914); Hamilton (1994); Wilson and Anhaeusser (1998); Government of the Northwest Territories (2001–2005); Even-Zohar (2002, 2007); BHP Billiton (2007); Rio Tinto Diamonds (2007a,b); and author's files.*
[b] *Values for sizes of pipes are modified from Janse (1996) and author's files; 1 ha (hectare) = 2.47 acres.*
[c] *Annual production figures are in thousands of carats (kct/yr); for the first seven mines listed and for the Mir open pit (all of which are now inactive), see notes "h" and "i."*
[d] *Values for grade in cpht (carats per hundred tonnes) and $/ct (U.S. dollars per carat) are approximate and vary from year to year as different types of ore are mined. Except for the first seven mines listed and for Mir (see notes "h" and "i"), the latest robust values are from 2003 and are extrapolated to 2005 by the author.*
[e] *Figures for annual value (in millions of U.S. dollars) were calculated by multiplying annual production (col. 7) by $/ct (col. 9).*
[f] *Total production figures (in millions of carats) were estimated by adding annual production figures, including from tailings, for the years of the life of the mine (col. 14).*
[g] *Total production values to date (in millions of U.S. dollars) are calculated by multiplying total production (col. 12) by value per carat (col. 9).*
[h] *The annual data for the five old Kimberley mines, Jagersfontein, and Koffiefontein (shaded in gray) are values chosen by the author from typical years of production throughout the life of the mine. Figures for grade were chosen likewise, and comparative values for $/ct were recalculated taking the De Beers mine as $/ct=$100.*
[i] *The Mir open pit closed in 1998; the figures for annual production, grade, and $/ct are derived from an average year in the 1980s.*
[j] *Future production for Argyle, Mir, and Udachnaya is for underground workings only.*

Years of Discovery and Opening (Cols. 5 and 6). In general, the time between discovery and commencement of mining varies from six to 10 years. This time frame has expanded in recent decades, as several stages of studies—e.g., scoping, pre-feasibility, feasibility, water use, and environmental and social impact—are required before authorities will issue permits and banks will lend money. The dates for Mbuji Maye appear to conflict because mining on associated alluvial deposits commenced in 1924, but the kimberlite deposits were not recognized until 1946 (Magnée, 1946).

Figure 12. The Mir pit in Yakutia, which ceased open-pit mining in 1998, was the first major diamond mine to be developed in what was then the Soviet Union. The discovery of Mir and several other large kimberlite pipes in this region represented the first meaningful non-African production to enter the world market in over 100 years. Photo taken in 1995 by James Shigley.

Annual Production (Col. 7). This figure is reported in thousands of carats recovered during 2005, except for the first seven mines listed and for the Mir open pit (all now inactive), for which—for comparison to currently active mines—a production value was chosen by the author from a past year that appeared typical. Annual productions vary through time and generally increase when the mine plants are expanded and decrease as the deposit is depleted. In some cases, the open pit becomes too deep and the pit walls need to be reconstructed (as happened to Argyle in 1999, when annual production fell from nearly 41 Mct/yr to 27 Mct/yr; see figure 2), or the mining method switches from open pit to underground (e.g., figure 14).

Grade (Col. 8). Grade—the yield of carats per 100 tonnes (cpht)—is the quotient of carats recovered during the year divided by tonnes (metric tons) of ore mined. It varies considerably between pipes. Grades

Figure 13. Canada's dramatic rise up the rankings in world diamond production has been the result of rich mines such as Diavik, shown here in a September 2006 image. A large dike had to be constructed to hold back the waters of Lac de Gras and allow safe open-pit mining of the A154 South and A154 North kimberlite pipes in the foreground. Just left of the A154 open pit, work has begun to expose the A418 pipe; production from that pipe is expected to begin in late 2007 or early 2008. Photo by Jiri Hermann, courtesy of Diavik Diamond Mines Inc.

also vary within a pipe. In many cases, the near-surface weathered rocks are higher in grade than the deeper rocks. For example, at Kimberley the grade was well over 200 cpht for the first 250 m of mining, but it had decreased to 40 cpht at closure in 1914 and averaged just over 100 cpht for the life of the mine (Janse, 1996).

Current Value (Cols. 9 and 10). Data for the average value per carat are not publicly listed by many mining companies, but they can be derived from the reports on sales of parcels of diamonds mined during the year and from estimates from diamond valuers and diamantaires who have inspected the run-of-mine product.

In some mines, such as Jagersfontein and Koffiefontein, the grade was very low (below 12 cpht), but the \$/ct was high (over \$200/ct); thus, the mines were viable. At Argyle the initial grade was very high (600 cpht) but the value per carat for the first production was very low (\$7/ct), and the mine would only be viable if operating costs could be kept low. This was done primarily by mining large volumes of ore, which kept the average cost per tonne down. In some mines—such as Jwaneng (Botswana), Mir (Siberia), Ekati (Canada), and Diavik (Canada)—both the grade and \$/ct are high, making them very profitable. Value per carat is influenced not only by the quality but also by the average size of the diamonds recovered. Generally, this is between 0.4 and 0.5 ct; diamonds over 2 ct are rare, amounting to only about 7% by weight (but 44% by value) of world production (Even-Zohar, 2002).

The product of multiplying the current grade (col. 8) by dollar value per carat (col. 9) gives the average value per tonne in the ground (\$/t; col. 10), which is one of the major factors in deciding if a project is economically viable. The second major factor is revenue, that is, the quotient of the value per tonne in the ground divided by the cost of mining it. Very approximately, this figure needs to be above one to make a viable mine, but several other factors (such as the time value of money, political risks, and environmental restrictions) must be factored into the decision to proceed with construction. In general, the \$/t varies between 30 and 100. Because data on mining cost per tonne are usually not publicly available, a column for revenue is not included.

Grade, value per carat, value per tonne, and ore reserves (see Past and Future Lives below) are all interrelated. Grade is typically a result of the recovery plant's cut-off screen size. If the bottom screen size is small (0.2 mm), many very small diamonds will be recovered in addition to commercially sized diamonds (1.5 to 2 mm) and the grade is high (as are ore reserves), but the cost of recovery goes up and the value per carat goes down because of the large quantity of small diamonds recovered from a tonne of ore. In general, most mines use bottom cut-off screen sizes between 1.5 and 2 mm, as the revenue from recovering more small diamonds usually does not compensate for the higher cost of recovery. However, this is a purely economic decision that has to be considered for each deposit on its own. Some mines have recently lowered this cut-off to 0.85–1.2 mm (see Tahera Diamond Corp., 2007), since the market for smaller rough has grown as cutters (mainly in Indian cottage industries) have become adept at manufacturing very small stones (Even Zohar, 2002). *Raising* the bottom cut-off, as Argyle did in 1994 (from 0.4 mm to 1.5 mm), lowers the grade, lowers ore reserves, decreases cost, but increases the value per carat and thus revenue. Likewise, costs increase when the top screen size is set high in order to recover possible large diamonds, but the revenue from these diamonds can compensate for the higher costs if the mine produces enough

Figure 14. Open pit mines eventually reach a depth at which the costs of further recovery by open-pit mining exceed the revenue produced. The mine will either close or shift to underground mining if there are sufficiently valuable reserves to make it economic. This miner working underground in the De Beers Finsch mine is using an automatically synchronized operated multiple drill in preparation for planting explosives to blast out another mass of kimberlite. Photo © Hervé Collart/Sygma/Corbis.

of them. A top size of 25 mm is most common, but for some mines that have historically produced large diamonds, such as Premier/Cullinan, the top screen size is 36 mm.

Past and Future Lives (Cols. 14 and 15). Several active mines—such as Murowa, Catoca, Jubileynaya, Nyurba, Ekati, and Diavik—have existed for less than 10 years, and this affects the data for total amount of diamonds recovered and their value, which are too low to give a representative rank. Therefore, those mines for which reliable data on future ore reserves are available (all except Jubileynaya and Nyurba) are included in the table for advanced projects (table 2). Most major mines, except those based on several small pipes, have life expectancies of 50–100 years (e.g., the Kimberley mines and Premier/Cullinan). However, most mining companies and analysts do not attempt to calculate ore reserves, and thus life, beyond 20 years because such estimates eventually become too speculative.

ADVANCED DIAMOND PROJECTS

During the last few years, four of the old underground De Beers mines in Africa have been closed, and several open-pit mines—Argyle in Australia and Mir (and possibly others, such as Udachnaya) in Russia—have reached or come close to their economic depth limit. It is therefore important to be aware of the development of advanced projects, which will contribute to the future supply of rough diamonds. It is hoped that data on planned underground mines in Russia eventually will also become available to complete these estimates.

Data for seven major advanced diamond projects and one planned underground mine are compiled in table 2. In contrast to many established mines, most companies now developing advanced projects publish data, updated regularly, on their capital cost of construction, year of projected opening, ore reserves, grade, value per carat, planned annual production, and life expectancy. This is because—in contrast to bygone times—many governmental or stock exchange regulations now require this information to protect shareholders and control wild fluctuations in stock prices. Such data also help government regulatory agencies draw up regional development plans. Note, however, that this is not the case for some countries, such as Russia in the recent past, where these data are traditionally considered privileged information and not disclosed, or for others where such regulations do not exist or are not enforced. Because pre-mine data for four young mines in table 1 are available (Ekati, Diavik,

TABLE 2. Historical and production data for eight advanced diamond projects and four young mines.[a]

Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9	Col. 10	Col. 11	Col. 12	Col. 13	Col. 14
Name of project/mine	Majority owner	Country	Size (ha)	Year of opening	Capital cost (M$)	Ore reserves (Mt)	Grade (cpht)	Reserves (Mct)	Value ($/ct	Value ($/t)	Value (M$)	Projected production (Mct/yr)	Projected life (yr)
Jericho	Tahera	Canada	3	2006	90	2.6	120	3.1	90	108	280	0.4	8
Snap Lake	De Beers	Canada	3	2007	580	23	146	33	76	111	2,500	1.5	20
Victor	De Beers	Canada	16	2008	750	27.4	23	6.3	450	105	2,850	0.6	12
Gahcho Kué	De Beers	Canada	3	2012	745	14.4	164	23.6	77	126	1,800	1	20
Grib	ADC/AGD	Russia	14	nd	nd	98	68	67	79	53	5,300	4	20
Arkhangelskaya	Severalmaz	Russia	15	2006	400	110	52	57	48	25	2,740	3	20
Camafuca	Endiama	Angola	160	2006	25	13	40	5.2	117	47	608	0.2	5
Argyle UG	Rio Tinto	Australia	12	2008	800	100	370	370	13	48	1,200	16	10
Ekati	BHPB	Canada	11	1998	880	78	109	85	84	92	7,100	5	17
Diavik	Rio Tinto	Canada	5	2003	1,170	27	395	107	62	245	6,300	8	20
Murowa	Rio Tinto	Zimbabwe	4	2004	61	19	90	17	70	63	1,200	0.5	17
Catoca	consortium	Angola	66	1997	nd	271	70	189	75	53	14,000	8	20

[a] *Sources: Hamilton (1994); De Beers Consolidated Mines (2001–2005); Government of the Northwest Territories (2001–2005); Even-Zohar (2002, 2007); Tahera Diamond Corp. (2006); BHP Billiton (2007); De Beers Group (2007a,b,c); Rio Tinto Diamonds (2007a,b,c); Severalmaz (2007); and author's files. All figures for reserves, grade, $/ct, and annual production are derived from bankable feasibility studies and will probably change during actual mining. Abbreviations used here are the same as for table 1; "nd" means no data are available. The rows shaded in blue—Ekati, Diavik, Murowa, and Catoca—are recently opened mines, included for comparison.*

Murowa, and Catoca), they have been included here for comparison.

The above notwithstanding, these figures must be viewed with some caution. In general, when a project becomes a mine, it is often found that estimated costs of construction are too low, so ore reserves are calculated on the low side to be safe. Further, grade and value per carat can prove to be quite different when mining has actually progressed during the first year or so, and the life of a mine is often extended as additional ore reserves are discovered while the mine is in operation.

Table 2 comprises 14 columns, some of which are described here in more detail.

Name of Prospect (Col. 1). Jericho is a small mine developed on a small pipe, but neighboring small pipes may be mined in the future. The data in this table are for Jericho pipe 1 only. (Jericho data are placed in this table even though it opened in August 2005, because it only came into actual production in March 2006; Tahera Diamond Corp., 2006). Snap Lake is not a near-vertical pipe but rather a shallowly inclined (about 15°) dike. Victor is a complex of three coalescing pipes that have different ore reserves, grades, and values per carat; data values are averaged over the whole pipe system. Gahcho Kué is a complex of four neighboring small pipes. The Arkhangelskaya pipe is the first of a group of five large pipes in the Lomonosov cluster to be developed into a mine. Camafuca is an elongated pipe (or the fusion of five pipes in a line) underneath the bed of the Chicapa River. Consequently, Camafuca I (the first stage of operation) will be developed as a dredging operation, lasting five years. "Argyle UG" represents data for the underground mine, which is planned to go into production in 2008.

Majority Owner (Col. 2). Three of the four advanced projects in Canada are owned by De Beers Canada. Development of the Russian Grib project has halted because of protracted litigation involving future ownership. This was to be vested in a new company, Almazny Bereg, in which the equities would be ADC (Canada-based Archangel Diamond Corp.) 40% and AGD (Arkhangelskgeodobycha) 60%, but AGD has so far refused to transfer title to the new company. Arkhangelskaya is 97% controlled by Severalmaz, a subsidiary of Alrosa; the rest is held by local authorities. De Beers once held an interest in this project, but it sold its equity to Severalmaz several years ago. Camafuca is owned by a consortium of Endiama (an Angolan parastatal company) 51%, Welox (a Lev Leviev company) 31%, and SouthernEra Diamonds (a Canada-based company) 18% free carried. (*Free carried* interest means that the company has equity in the development of the project, but does not have to contribute to the cost of development. Such interest either ends at the "decision to mine," when the risk has virtually disappeared, or lasts to the commencement of mining, after which the cost of contributing can be subtracted from the profit from mining.)

Size (Col. 4). The size given for Snap Lake is arbitrary; while its surface footprint is quite small, the dike extends underground for an as-yet-undetermined distance of at least 2 km down dip. The sizes of Gahcho Kué, Ekati, Diavik, and Murowa are a total for several small pipes, not all of which are currently mined (but are likely to be mined in the future).

Year of Opening (Col. 5). The scheduled year of opening for the Grib pipe cannot be given, again because of the litigation over ownership. Arkhangelskaya started overburden stripping in 2003; actual mining began on a small scale in 2006.

Capital Cost (Col. 6). This figure, often called *capex* (capital expenditure), represents construction costs only. Thus, the capital costs for Grib cannot be stated, as no mine construction has taken place. The capital costs for Arkhangelskaya are for the first stage of mining the pipe itself. The second stage, constructing a larger plant and a larger open pit in which the Arkhangelskaya pipe and the adjacent Karpinskaya 1 and 2 pipes will be mined, will begin in late 2007. The capex for Diavik is high because the pipes are located under water in Lac de Gras, which was too large to simply drain. Thus, development of Diavik required the construction of large encircling dikes (again, see figure 13), which were expensive to construct because of severe climatic conditions and environmental issues. In contrast, the first stage for Camafuca is a dredging operation, which is relatively simple and has a low cost compared to open-pit mining. Murowa is on land in an area of easy access and requires only small open pits; both African sites (unlike the Canadian mines) have comparatively low labor costs.

Ore Reserves (Col. 7). Given here in millions of tonnes (Mt), reserves are determined by sampling, which usually involves drilling many holes over a

TABLE 3. Historical and contemporary production data and rankings for 27 diamond producing countries: Totals to 2005.[a]

Country	Year 1st diamond[b]	Year 1st kimberlite[b]	Year 1st mining[c]	Total prod. (to 2005) (Mct)[d]	Total prod. (2001–05) (Mct)[d]	% World prod. (to 2005)[e]	% World prod. (2001–05)[e]	Rank in world prod. (to 2005)	Rank in world prod. (2001–05)	Value/ct (to 2005) ($/ct)[f]	Value/ct ($/ct) (2001–05)[f]
South Africa	1867	1870	1870	614	65	15	9	4	5	95	90
SWA/Namibia	1908	1899	1908	94	8	2	1	8	8	373	373
Botswana	1959	1966	1970	485	148	12	19	5	3	90	90
Rhodesia/Zimbabwe	1903	1907	1913	1.5	0.3			20	19	145	145
Swaziland	1973	1973	1984	0.6	nd			24	25	90	90
Lesotho	1955	1939	1968	0.6	0.08			23	22	1,000	1,000
Southern Africa				1,196	221	29	29				
Angola	1912	1952	1916	111	31	3	4	7	7	155	155
Congo/Zaire/DRC	1907	1946	1913	991	114	25	15	1	4	20	20
Congo Republic	1932	nd	nd	30	nd						
Gabon	1939	1946	nd	4	nd						
CAR	1914	nd	1930	21	2	0.5		15	13	160	160
Tanzania	1910	1925	1925	20	1	0.5		14	16	120	120
Central Africa				1,177	148	29	20				
Guinea	1932	1952	1936	14	2.5			17	11	150	150
Sierra Leone	1930	1948	1932	57	2.5	1		9	10	220	220
Liberia	1910	1955	1955	21	0.5			13	17	100	100
Ivory Coast	1928	1960	1958	8	1.5			18	15	140	140
Ghana	1919	1994	1920	114	5	3	1	6	9	30	30
West Africa				214	12	5	2				
Brazil	1725	1973	1727	36	2.4	1		11	12	75	75
Guyana	1887	nd	1890	6	1.5			19	14	95	95
Venezuela	1883	1982	1913	16	0.3			16	19	60	60
South America				58	4	2					
Canada	1971	1948	1998	51	45	1	6	10	6	115	115
United States	1843	1885	1921	<1	nd			25	25	200	200
USSR/Russia	1829	1954	1960	684	175	16	23	3	1	55	60
Australia	1851	1972	1883	720	154	17	20	2	2	17	17
China	1870	1965	1980	13	0.4	1		12	18	20	20
India	antiquity	1870	antiquity	1	0.4			21	21	165	165
Indonesia	800	nd	800	1	0.01			21	23	280	280
Total global				4,115	761	100	100			67	65
plus 10% illicit				~4,500	~840					67	65

[a] *Sources:* The Mineral Industry *(1870–1934);* Mineral Resources of the United States *(1870–1934); Wagner (1914);* Minerals Yearbook *(1934–2005); and Kimberley Process Certification Scheme (2004, 2005). Abbreviations used here are the same as for table 1; "nd" means no data are available.*
[b] *Sources: Janse and Sheahan (1995); Kjarsgaard and Levinson (2002).*
[c] *Note that for several countries, mining began, closed, and sometimes reopened, e.g., Zimbabwe (Somabula, 1913–1930; River Ranch, 1992–1998; Murowa, 2004–present); Lesotho (Letseng, 1968–1982, reopened 2004); United States (Arkansas, 1921–1924; Kelsey Lake, 1995–1996); Russia (Urals, 1890–1917; Siberia, 1960–present); Australia (New South Wales, 1883–1948; Argyle, 1980–present).*
[d] *Calculated by summing up each country's annual production; illicit production is added as 10% of total global production.*

specific grid pattern into a pipe to a certain depth and analyzing the number and value of the diamonds recovered from the drill cores (in some cases, trial mining may be used as well). The larger the diameter of the cores and the more numerous the holes, the better the ore-reserve calculation will be. Also, the deeper the holes, the more potential ore can be outlined (i.e., as a three-dimensional model of reserves) for further calculations. However, drill diameter and depth are constrained by practical and technical parameters, and there are strict guidelines for the calculation of ore reserves. There is also a practical limit to the depth to which ore reserves can be calculated. Generally, a pipe narrows to a fissure at depth, which results in smaller volumes in cross-cut or plan and thus higher costs of mining; at some point, the mining costs will exceed the value per tonne of ore. Also, the deeper the reserves are projected, the less reliable the results are. Of course, the larger the pipe's surface outcrop, the larger the cross-cut volumes at depth will be, so large pipes can have ore reserves calculated as deep as 500 m, which is

Total value (to 2005) (B$)[f]	Total value (2001–05) (B$)[f]	% World value (to 2005)[e]	% World value (2001–05)[e]	Rank in value (to 2005)	Rank in value (2001–05)
58	5.9	22	13	1	3
35	3	13	5	4	6
45	13.3	17	26	2	1
0.2	0.04			21	20
0.05				24	24
0.6	0.08			23	17
139	22	52	44		
17	4.8	6	10	7	5
21	2.3	8	5	5	8
3.3	0.3	1	1	11	11
2.5	0.1	1		12	15
44	7.5	16	15		
2	0.4	1	1	10	10
12.5	0.5	5	1	6	9
2	0.05	1		13	19
1	0.2			18	13
3.5	0.15	1		14	14
21	1.3	8	2		
3	0.2	1		15	12
1	0.1	0		19	16
1	0.02	1		16	21
5	0.3	2	1		
6	5.2	3	11	9	4
<0.1				25	25
38	10.5	14	21	3	2
12	2.6	5	5	8	7
0.3				17	23
0.2	0.07			20	18
0.3				22	22
266	49.5	100	100		

[e] *Figures in the percentage columns may not appear to add up correctly, as there are several countries in the list with less than 1%.*

[f] *Given as present-day values to compare the relative significance of countries only; they are not the values at the time of each year's production.*

the case for the Arkhangelskaya pipe, where ore reserves were calculated down to 460 m. In practice, though, ore-reserve projections generally are not carried beyond 100–150 m below surface level.

Value (Cols. 10–12). The value per carat for Victor is very high, as the run-of-mine diamonds recovered thus far are remarkable for their white color, with very few brown or yellow diamonds. The value for Camafuca I is also high for pipe diamonds, but in this case the figures may include some proportion of alluvial diamonds recovered in the dredging operation. The high overall value for Grib ($5.3 billion) makes it clear why ADC persists in its legal battles to retain its part ownership in the project. The large Catoca mine has a very high potential value ($14 billion), while Ekati and Diavik are outstanding at $7.1 billion and $6.3 billion.

The value for Arkhangelskaya ($48/ct) multiplied by grade (52 cpht) gives a suspiciously low value per tonne: $25/t. In general, new mines are not considered economic below $40/t, which makes this figure an obvious discrepancy. Unofficial sources say that the value per carat of Arkhangelskaya is in fact similar to that for Grib (~$80/ct), which would increase the figure to $42/t, more in line with general economic considerations.

Projected Production (Col. 13). Grib and Arkhangelskaya should be significant mines. Projected annual production for Grib is 4 Mct. For Arkhangelskaya, plans call for a large recovery plant with a throughput of 5.6 Mt annually; if the grade (52 cpht) applies to all three pipes projected to be mined, then an annual production of about 3 Mct can be assumed, which will commence in 2010. Catoca is still increasing its annual production, which may eventually reach 8 Mct. Argyle UG will have a very high annual production, though with a comparatively low total value of $1.2 billion.

Projected Life (Col. 14). The Jericho mine is projected to be relatively short lived, at eight years, but additional reserves may be discovered in neighboring pipes. The five-year life for Camafuca I is only for the dredging operation, during which time the reserves and a mining plan covering all or part of the pipe will be established, for a projected life of at least 20 years.

THE TWENTY-SEVEN DIAMOND PRODUCING COUNTRIES

Data and statistics for 27 diamond-producing countries (for both total production and 2001–2005) are listed in table 3. Not included are countries for which the occurrence of diamonds or kimberlite/lamproite has been recorded but no diamonds are mined (e.g., Algeria, Finland, Greenland, Kenya, Mali, Mauritania, Mozambique, and Thailand), or for countries from which diamond exports are recorded but no diamond mines are known (e.g., Burkina Faso, Guinea-Bissau, Nigeria, Rwanda,

Figure 15. Not all diamond production has come from organized mining. A significant—though difficult to quantify—percentage has come from informal, or "illicit," mining by artisanal means. This 1996 photo taken in Sierra Leone shows local diggers using primitive methods to extract diamond-bearing gravels. The diamonds produced are often smuggled out of mining areas to avoid taxes or to obtain higher prices. Photo © Patrick Robert/Sygma/Corbis.

Senegal, and Uganda). The Republic of Congo (Congo-Brazzaville) and Gabon are partially included in the list, as their diamond outputs are recorded in *Minerals Yearbook* for some years, but alleged production for both has been included in the total for the Congo/Zaire/DRC in calculating percentages, rank, and value.

Illicit Mining. It is important to note again that the amount of illicit or informal production can be estimated only very broadly, since it results from the work of artisanal diggers (again, see figure 7, and figure 15), who are typically unlicensed and unregulated by official governmental agencies, and work mainly on alluvial deposits or on the surface portions of pipes or fissures (dikes). Their output may be purchased by diamond buyers (who also may or may not be licensed) on the spot, but more often it is smuggled to another country to avoid paying taxes or to obtain a higher price in a more stable currency (Even-Zohar, 2002). The amount of illicit digging has varied greatly over time. It was high in Sierra Leone in the 1950s (Laan, 1965; Hall, 1968) and very high in Angola, Zaire/DRC, and Sierra Leone in the 1990s, often far outstripping the official or formal production (Partnership Africa Canada, 2004a,b, 2005a,b, 2006). In the 1990s, a large part of the proceeds of illicit production was used to purchase arms and supplies to equip rebel forces, which often occupied the alluvial diamond fields in these countries and engaged in mining by forced local labor. (This type of illicit production gave rise to the terms *blood diamonds* or *conflict diamonds*, further discussion of which is beyond the scope of this article.) The percentage of illicit digging is high in some places, anywhere from 20% to 100%, while in more regulated countries (such as Canada) it is low or nearly nonexistent. Consequently, a modest (and *arbitrary*) 10% figure for illicit digging has been added to total global production.

Historical Production. As noted earlier, historical production before 1870 was minor in today's terms and was restricted primarily to India and Brazil, with some production from Indonesia. Information on diamond mining before the mid-1800s can be found in Lenzen (1970), Levinson et al. (1992), and Janse (1996), among other authorities. Diamond mining began in India in antiquity (and was first recorded in a Sanskrit text, the *Arthasastra*, written by Kautilya in the late fourth century BC; Rangarajan, 1992), with minor production from Borneo beginning about 800 AD (Legrand, 1980). Diamonds only became important in the world economy with the commencement of mining in Brazil in the mid-1700s (Lenzen, 1970).

The most important historical producer was South Africa, which dominated the market from 1872 to 1932. Over the full period 1870–2005, it ranks fourth in carat weight and first in value because of its long history of production. South-West Africa/Namibia ranks eighth in carat weight but fourth in value due to the high quality of diamonds in the beach deposits (figure 16).

From 1932 to 1970, the Congo, Angola, and West Africa dominated diamond production. The Congo/Zaire/DRC ranks first in carat weight up to

Figure 16. Namibia's beach mines, despite their relatively small production by weight, have long been an important contributor to the world market because of the very high value of the diamonds they produce. The diamonds are recovered from crevices in the bedrock after the overlying sand has been removed, as shown here in 2005. Photo by Robert Weldon.

2005, but due to the low quality of diamonds from Mbuji Maye, it ranks only fifth in value. Sierra Leone and Guinea rank ninth and 17th in carat weight, but sixth and 10th in value due to the high quality of their diamonds. Ghana ranks sixth in carat weight and 14th in value, again due to the relatively small size and consequent low value of its diamonds. Angola ranks seventh in both carat weight and value over the life of mining there.

From 1970 to 1985, legitimate production from Zaire and West Africa declined because of political upheavals, while newly commenced production from kimberlite pipes in Siberia and Botswana, and increasing production in South Africa, became dominant. The Soviet Union/Russia ranks third in both carat weight and in value, while Botswana ranks fifth in carat weight and second in value.

Production from Australia's Argyle diamond mine entered the market in 1986 and soon introduced a large volume of industrial diamonds. The market absorbed this amount partly by developing the near-gem category of diamonds and partly by scaling back production in South Africa. Consequently, while Australia ranks second in carat weight, it reaches only eighth in value. Canada's production of high-quality diamonds entered the market in 1999, and its rank of 10th in carat weight and ninth in value are low only because of its recent entry.

Brazil dominated world production from 1750 to 1870, but it has been far less significant since that period. Virtually every major river system in Brazil contains alluvial diamonds, but the country currently has no diamond mines developed on a kimberlite or lamproite pipe. All major production has come from alluvial localities in Minas Gerais and Bahia, with lesser production from Roraima. Recently, the 30,000 ct/yr Chapada alluvial project in Mato Grosso commenced mining, while prospecting for economic kimberlites in Bahia, Minas Gerais, and Rondonia has shown promising results. Brazil's total historical production, as compiled from the U.S. source publications used, is 55 Mct, but Barbosa (1991) estimated diamond production up to 1985 as 100 Mct (too neat a figure for this author's liking). As about 20 Mct were produced from 1985 to 2005, the total production for Brazil would be 120 Mct if Barbosa's figure is accepted. (Note: This illustrates the uncertainty involved in compiling the totals of individual countries, but it does not significantly affect the global total of 4.5 Bct.) Brazil ranks 11th in lifetime carat weight, but would replace Angola as sixth if the higher figure was valid.

Other minor producers include British Guiana (now Guyana) and Venezuela, which commenced production in the late 1890s; the Central African Republic and Tanzania, beginning in the 1930s; and China in the 1980s; however, their combined production has never reached more than 1% by weight and 2% by value of modern global production.

Contemporary Production. Data for 2001–2005 give a modern perspective to the relative significance of the producing countries. Russia now ranks first in carat weight and second in value, while Botswana is first in value though third in carat weight, just behind Australia. In the future, Botswana will probably exceed Australia in carat weight, since its production is still increasing while Australia's is declining as Argyle switches to underground production. Botswana will probably stay first in value, as Russia has to overcome a gap of nearly $5 billion to catch up. South Africa has not changed much, with its rank of fifth in carat weight and third in value, but the new success story is Canada, which after only a few years is fourth in value and sixth in carat weight and may overtake South Africa in the near future.

The DRC is now fourth in carat weight and eighth in value and will probably maintain these rankings, since production is likely to increase as its civil disorders have diminished. Also, with the western and eastern Kasai being intensively prospected, new discoveries are likely to be made. Angola ranks seventh in carat weight and fifth in value and is climbing through the ranks, as production from the large Catoca pipe mine is still increasing and additional pipe mines (Camafuca, Camatchia, and Camagico; data for the last two have not been released) will come on stream in the future. Namibia ranks eighth in carat weight and, despite a modest 8 Mct, sixth in value due to the quality of its diamonds. Likewise, the high value of diamonds from Sierra Leone gives this country a rank of ninth in value for a carat weight of 2.5 Mct. The unknown player is China, for which no robust data are available. According to the Kimberley Process figures, its total production has been only 2.5 Mct, and it thus has a very low rank in weight and value. However, diamonds are being aggressively sought in China, and an important discovery could change the situation greatly.

Global production for 2001–2005 was 840 Mct with a value of $55 billion, for an average value per carat of $65.

CONCLUSION

The history of modern diamond production spans 135 years. Although alluvial deposits have been known since antiquity, diamond production from primary deposits (kimberlites and lamproites) commenced only in the 1870s and has increased by leaps and bounds ever since to a staggering total of 4.5 billion carats.

It is interesting to note that nearly 20% of this total was produced during the last five years. During the last 10, nine new mines have commenced production or come very close: Nyurba and Arkhangelskaya (Russia); Ekati, Diavik, and Jericho (Canada); Murowa (Zimbabwe); and Catoca, Camafuca, Camatchia, and Camagico (Angola). Four additional advanced projects are waiting in the wings: Snap Lake, Victor, and Gahcho Kué (Canada); and Grib (Russia). This will more than counterbalance the closing of seven old mines. As it is predicted that demand for rough will outstrip production during the next five years, and a gap of $20 million in supply and demand by 2015 has been quoted (Even-Zohar, 2007), this new production can easily be accommodated in the diamond market.

Primary deposits were first discovered in South Africa and exploration spread from there to identify diamond-producing pipes in Tanzania (1940s), Siberia (1950s), Botswana (1960s), Angola (1970s), Australia and northwest Russia (1980s), and Canada and northwest Russia (1990s). Thus, it appears that at least one major diamond mine or field has been discovered every 10 years since the 1940s. If this trend continues, then a major new discovery is imminent. This may perhaps be in China, where prospecting for diamonds is being vigorously pursued at present.

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