Marine Mining of Diamonds Off the West Coast of Southern Africa

By John J. Gurney, Alfred A. Levinson, and H. Stuart Smith

A vast resource of gem-quality diamonds exists off the west coast of southern Africa. Over the course of millions of years, many diamond-bearing kimberlite pipes in the Orange River drainage basin have been extensively eroded and the released diamonds transported to the west coast. Raised marine deposits now on land have yielded almost 100 million carats of predominantly gem diamonds; similar marine deposits and feeder channels are now known to exist offshore. Techniques for exploiting the offshore resources have been proved on a small scale in shallow (<15 m) waters. New technological developments in underwater mining systems have progressed to the point where mining has commenced in deep (about 100 m) Namibian waters. It is anticipated that production of diamonds from the sea will increase substantially in the future.

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Because diamonds are the heart of the jewelry trade, the continued supply of fine diamonds from the mines into the marketplace is of critical importance to this industry. According to the Central Selling Organisation, about one-eighth (approximately 13 million carats) of the diamonds now mined annually eventually end up in jewelry (figure 1). Yet for the largest producer of diamonds in 1990, the Argyle mine in Western Australia (36 million carats), fine gem-quality diamonds represented only about 5% of the total yield. In addition, older deposits of gem-quality diamonds are gradually being exhausted. For example, the total production at the Kimberley pool of mines was 1,173,042 ct in 1980 but only 574,188 ct in 1990 (De Beers Consolidated Mines Ltd., 1981, 1991).

In the future, the steady supply of gem diamonds to the jewelry industry will depend on the discovery of new deposits and the engineering expertise to extract the diamonds economically. Because the search for new diamond reserves in conventional primary (e.g., kimberlite or lamproite) or secondary (e.g., alluvial) deposits is very expensive and generally has a low probability of success, mining concerns are looking to the extraction of diamonds from known, if unconventional, sources, such as the undersea deposits off the west coasts of South Africa and Namibia.

These exceptional deposits of gem-quality diamonds have been known for some time, but they have not been exploited fully because of the technological difficulties of recovery. Estimates of the amount of diamonds range upward from a conservative 1.5 billion carats, of which approximately 90%-95% are gem quality (Wilson, 1972; Meyer, 1991). Thus, the marine deposits off southwestern Africa apparently contain at least 100 times as many gem diamonds (by weight) as are presently being used annually in jewelry. In addition, this source contains a

Figure 1. This is a representative sample of diamonds produced from concession 6(A) near Koingnaas, South Africa. Most of the diamonds are in the size range 0.1 to 0.6 ct, and exhibit excellent shape and overall quality. Photo courtesy of Benguela Concessions.

high percentage of rough suitable to cut the small (1/4 to 3/4-ct) gems that are very important in the jewelry industry.

The economic and technological climate now permits mining of these deposits. Although the problems of recovery are major, as will become clear from the discussion below, considerable progress has been made in recent years to establish a viable extraction industry. The financial risks continue to be significant, but the vast reserves hold extraordinary promise.

HISTORY

The first discovery of diamonds related to marine deposition in southern Africa was on land in 1908 near Luderitz, Namibia (figure 2); the history of this discovery is described in detail by Levinson (1983). This led to the subsequent discovery of rich diamond fields along the west coast of then German South West Africa, and the development, within a few years, of a huge industry in this arid, inhospitable region. Later, diamonds were also discovered and mined elsewhere along the vast coastline from south of the Olifants River in South Africa to north of Hottentot Bay in Namibia, a distance of about 1,000 km. Although the great majority have been mined on what is now land (on beaches and raised terraces), the diamonds were originally deposited under water, having been carried

Figure 2. Large quantities of diamonds have been found both onshore and, more recently, offshore the west coasts of South Africa and Namibia. Noted here are the key rivers and towns involved in the distribution and recovery of the marine diamonds.

into the sea by rivers at a time when the oceans were at a higher level.

The significantly more difficult exploration for diamonds on beaches still under water was started by two small companies in 1954. During the period 1961 to 1965, these efforts were greatly expanded by a Texan, Sam Collins, through the Marine Diamond Corporation (MDC). MDC was subsequently acquired by De Beers and is essentially the forerunner of the currently very active De Beers Marine (Pty) Ltd., which now operates prospecting and trial-mining vessels in Namibian and South African waters.

No other mining company in this field approaches the size and scope of De Beers Marine, which dominates the available offshore lease areas of Namibia and South Africa (figure 3) through holdings and joint-venture agreements. In South Africa, the activity of De Beers Marine is confined essentially to water deeper than 100 m (the C concession zones; again, see figure 3).

Two other groups, Alexcor and Benguela Concessions (Benco), accounted for more than 50% of the marine diamonds produced annually from the Namaqualand sea diamond operations in 1989 and 1990. Several minor contractors provide the balance of the production from South African waters. Most of the marine diamonds produced in South African waters (>70% in 1990) are won from gravel recoveries close to the mouths of the Orange, Buffels, and Olifants rivers.

In Namibia, offshore diamond mining is dominated by Consolidated Diamond Mining (Pty) Ltd. (CDM), a wholly-owned subsidiary of De Beers Consolidated Mines Ltd., which controls those offshore mining areas from the mouth of the Orange River to Luderitz (Dias Point) that lie within Namibian territorial waters. CDM also controls areas farther north, notably at Hottentot Bay.

The Namibian West Coast Diamond Company has an offshore diamond-mining area that extends from Dias Point almost to Hottentot Bay, which it works actively on a small scale. In 1990, several other offshore diamond-prospecting leases were granted by Namibian authorities, but no significant recoveries have yet been reported from these new leases.

Ocean Diamond Mining Ltd. (ODM) is entitled to recover diamonds from the territorial waters around 12 small islands off the Namibian coast that belong to the Republic of South Africa. These rights, associated with what are referred to as the "guano islands," belong to Eiland Diamante (a subsidiary of Trans Hex), which entered into an agreement with ODM in the early 1980s that allows the latter to exploit the rights for a small royalty payment.

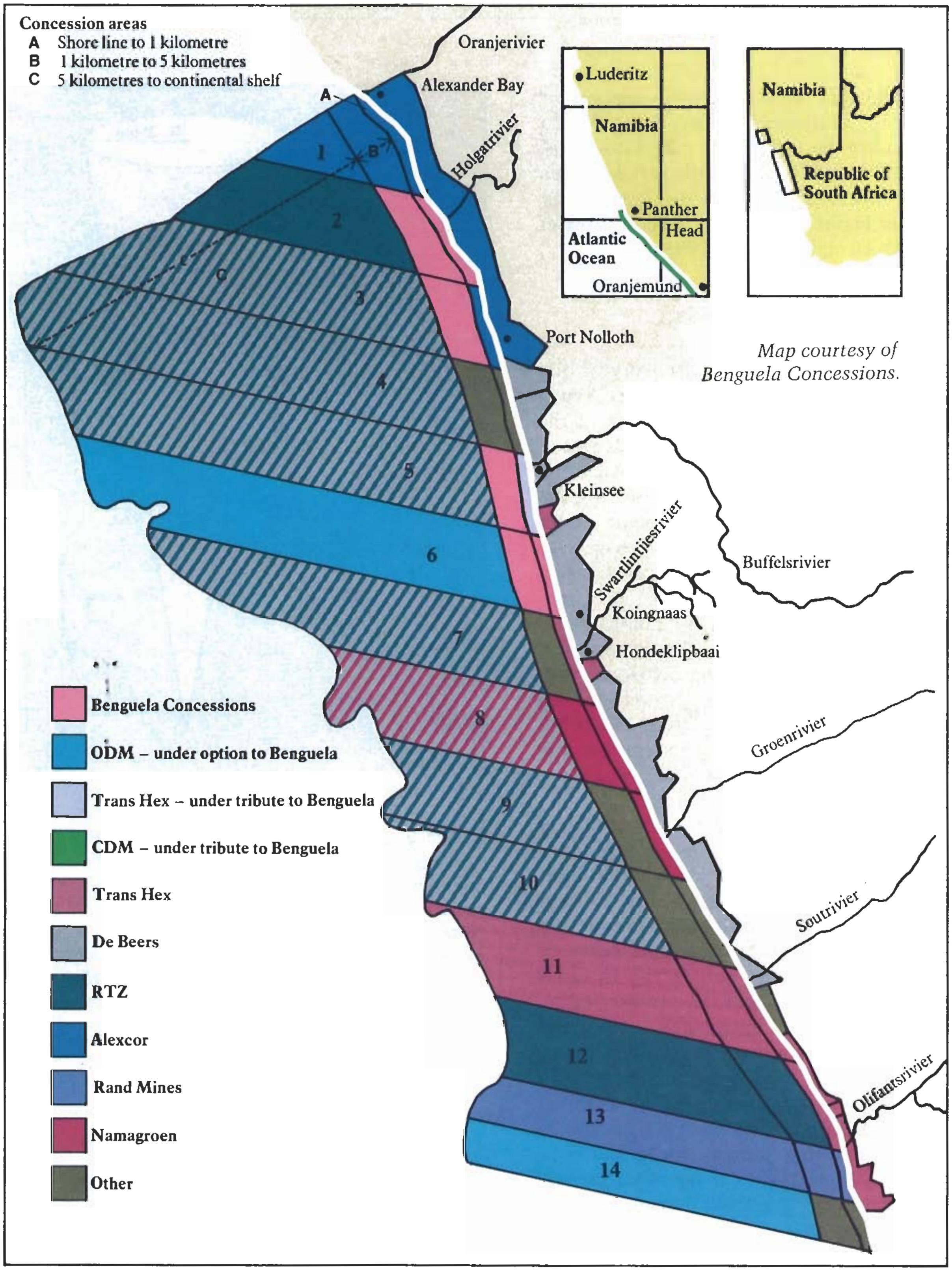

Figure 3. The offshore diamond mining lease areas in South African waters in 1991 are identified. The coastal shelf waters have been divided into 20 contiguous, parallel strips; numbers 1 to 14 (shown here) have been further subdivided into three units (zones)—A, B, and C—according to their distance from the shoreline, in successively deeper waters. Area A is 1 km wide and roughly parallel to the coast, with its inshore boundary 30 m seaward of the low-tide mark. Area B is seaward of A and lies from 1 to 5 km offshore. Zone C comprises the rest of the continental shelf and is in deeper water, generally greater than 100 m. Onshore concessions are also shown, to the right of the thick white (shore) line. Zones with diagonal stripes are controlled by De Beers. The insert of Namibia from Oranjemund to Luderitz shows the area under tribute to Benguela Concessions.

Further details on the historic aspects of marine coastal diamonds off southern Africa may be found in the articles by the Geological Department, De Beers Consolidated Mines (1976), Van Wyk and Pienaar (1986), and Meyer (1991), and in books by Wilson (1982), Levinson (1983), and Joyce and Scannell (1988).

FORMATION OF THE MARINE DIAMOND DEPOSITS

Source of the Diamonds. The discovery of diamonds on the west coast of southern Africa inevitably led to a search for their origin in the immediate hinterland. Only one reputable geologist, ironically the highly respected Dr. H. Merensky, who is credited with discovering the major South African platinum deposits, ever seriously believed that the primary origin for these diamonds was submarine kimberlites in the Atlantic Ocean. All others, particularly consulting geologist Dr. E. Reuning, postulated a primary origin somewhere in the continental interior from which, following erosional processes, the diamonds were transported to the sea by such rivers as the Orange, Buffels, and tributaries to the Olifants. (The literature on this subject is voluminous, but a comprehensive review can be found in Williams, 1932.)

It has long been known that the primary sources of most diamonds are kimberlite pipes intruded into older parts of the continental interior, that is, cratons (for a review of this subject, see Kirkley et al., 1991). Most of the diamondiferous kimberlites in southern Africa are between 80 and 120 million years old. In the interval between their formation and the present, many of these pipes have been extensively eroded and their diamonds released for transportation into secondary (alluvial, beach, etc.) deposits. In some cases, such as around Kimberley, as much as 1,400 m of the original depth of the numerous pipes and surrounding country rocks has been eroded (Kirkley et al., 1991). If we consider only the Kimberley mine ("Big Hole") as an example, and take into account its shape (cone), dimensions (depth of mining, surface area), and amount of erosion since emplacement, calculations (figure 4) show that about 34 times the volume of rock mined has actually been eroded. The volume of rock mined yielded about 14.5 million carats of diamonds before mining ceased in 1914. Assuming that the pipe had a uniform content of diamonds throughout (a conservative assumption because diamond grades tend to increase, and pipes tend to flare out, toward the top), then about 500 million carats were eroded away from this one pipe alone and released into

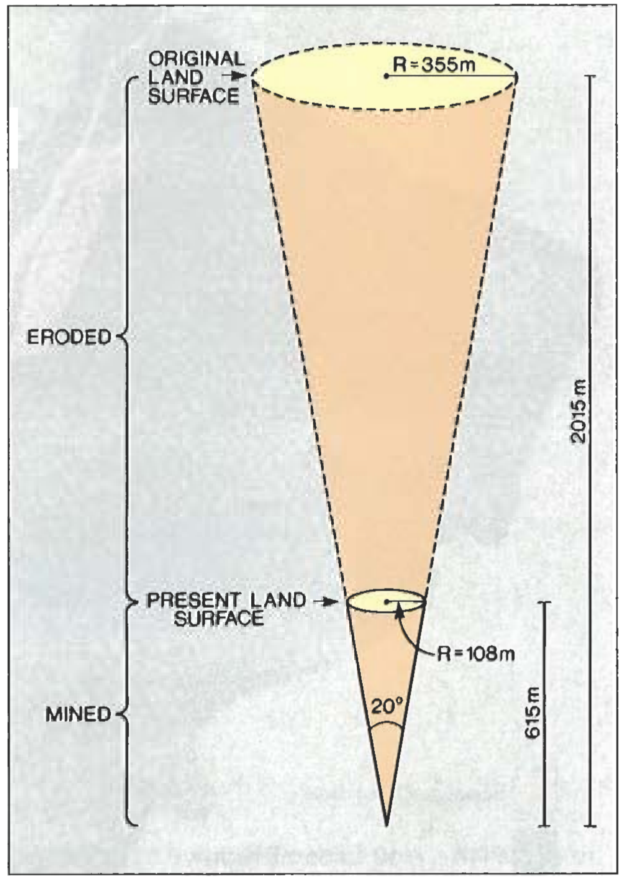

Figure 4. On calculating the volume of rock removed from the Kimberley mine (the "Big Hole") in Kimberley, South Africa, the assumption can be made that the shape of the pipe approximates a cone whose volume can be determined from the formula $V = (\pi/3)R^2H$ (where R = radius and H = height). For this example, the depth of mining is taken as 615 m and the depth of erosion as 1400 m (2015–615 = 1400). These and other dimensions are shown on the illustration. From these data, calculations show that the volume of rock eroded (about 258 million cubic meters) is about 34 times as large as the volume of rock mined (about 7.5 million cubic meters), which we know yielded about 14.5 million carats of diamonds before mining ended in 1914.

the drainage basin. There are an estimated 3,000 kimberlite pipes and dikes in southern Africa and, although not all contain diamonds, erosion of their combined original contents (by even the most conservative estimates) is sufficient to far exceed the 1.5 billion carats of diamonds postulated for the marine deposits. This last figure allows for the destruction of many flawed, heavily included, lower-clarity stones *en route* to the sea.

The dominant drainage in southern Africa has been westward since the emplacement of most of the known kimberlites as long ago as 100 million years (Dingle and Hendry, 1984). Currently, sediment transportation from the kimberlites in the interior of southern Africa is confined to the Orange River drainage system (figure 5). However, over time, changes in climate and geomorphology have had dramatic effects on river courses, rates of flow, volumes of runoff, rates of erosion, etc. For at least the last 80 million years, the Orange River has transported sediments from the continental interior to the Atlantic ocean through two main courses, which have led to the deposition of diamondiferous sediments at different positions along the coastline (figure 6). It is likely that, for 45 million years (from 20 to 65 million years before the present), the mouth of the Orange River was located about 400 km south of its current location, in the area that now forms the mouth of the Olifants River (again, see Dingle and Hendry, 1984).

Diamonds have also been transported to the sea along shorter river courses, such as the Buffels, which have cut back into the old interior land surfaces and reworked fossil gravels. Other geologic situations—for example, where small rivers have reworked old exposed beaches to concentrate diamonds into new deposits—are also known but are beyond the scope of this report.

From what has been discussed to this point, it should be clear that alluvial diamonds can be found anywhere along the extensive Orange River drainage basin between the primary kimberlite sources and the point at which the diamonds entered the sea. In fact, inland alluvial diggings have been important in South Africa since the discovery of the primary deposits. Nevertheless, of all the gem diamonds that have been released into the drainage basin and have survived the erosional processes, we believe that less than 10% are on land; the great majority have traveled to the sea.

Marine Distribution. Wave action is a powerful agent for transporting material, particularly on the west coasts of South Africa and Namibia, where the winter months are characterized by

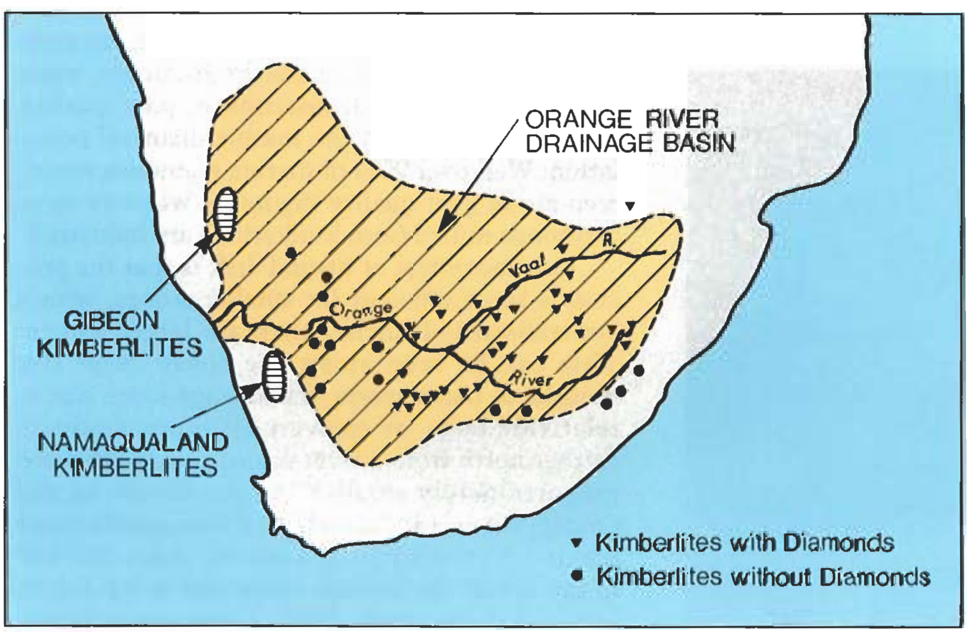

Figure 5. This map of southern Africa shows the present Orange River drainage basin, including the present position of the Orange and Vaal rivers. Also shown are the locations of kimberlites with and without diamonds as well as the Gibeon and Namaqualand kimberlite fields, both of which are barren of diamonds. Alluvial diamonds have been found throughout the drainage basin, but the vast majority have been transported westward to the Atlantic Ocean.

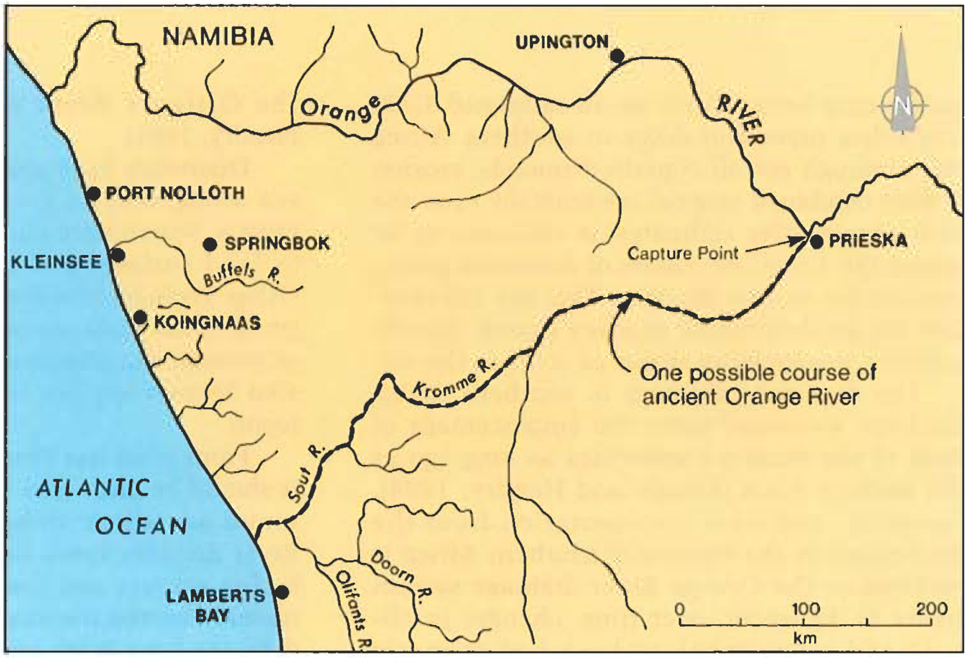

Figure 6. The Orange River drainage system has migrated over time. One possible course in the past is in the vicinity of the present Kromme, Sout, and Olifants rivers. This possible ancient course accounts for marine diamonds being found far to the south of the mouth of the present Orange River.

wild and stormy seas (figure 7). The waves are generated in the South Atlantic and attack the coastline from the southwest, reinforced by the prevailing southwesterly wind. This results in a strong northerly littoral (i.e., along the shore) drift of sediments.

Figure 7. The typical wave action seen here along the west coast of South Africa (in concession 9A) illustrates the powerful force that continually moves the diamonds northward along the shore.

This wave and wind regime has existed along the west coast of southern Africa for millions of years. Thus, littoral drift has played a major role in distributing diamonds along the coast. Coarse sediment (sand and gravel plus diamonds) transported to the sea by rivers is steadily moved northward from the mouths of those rivers. As diamonds are chemically inert and hard, they are only minimally subject to mechanical abrasion or weathering during transportation along the coast. On the other hand, poorly shaped and strongly fractured stones that survived river transport to reach the ocean are preferentially destroyed in the high-energy wave environment. This destruction of poor-quality stones is reflected in the marine diamond population: Well over 90% of marine diamonds recovered are of gem quality (figure 8), whereas most diamonds mined from kimberlites are industrial.

Another effect of littoral drift is that the process is more efficient for smaller stones, which are transported further than are larger stones. This can be seen along the coast: Near the mouths of major rivers, the average stone size is relatively large; at recovery sites progressively further north from a river mouth, stone sizes are proportionately smaller. At the mouth of the Orange River, for example, the average diamond size is 1.5 ct, whereas at Luderitz, some 200 km to the north, the average stone size is 0.1–0.2 ct (figure 9; Sutherland, 1982). Large stones found at the mouths of the Olifants, Groen, and Buffels Rivers are similar in size to those found at the mouth of the Orange River. Thus, the diamonds are sorted and sized during, and as a result of, marine transportation subsequent to their initial deposition into the ocean.

Diamonds have a higher specific gravity (3.52) than do most common minerals (e.g., quartz at 2.66) and rock pebbles. Consequently, they tend to gravitate, along with other relatively heavy minerals, to the base of trap sites such as gullies, potholes, south-facing bays, and old beach levels (figure 10). In some instances, spectacular grades occur where the sea has concentrated thousands of carats of diamonds in very small areas. In general, the smaller the average size of the diamonds, the more evenly the stones are distributed over a beach level. Bigger diamonds are sometimes found in "jackpot" trap sites—usually small, very specific features with only a few cubic meters of gravel (again, see figure 8). Although the smaller diamonds are less valuable, they are more abundant.

Sea levels have fluctuated widely in the last 100 million years or so, from more than 500 m below present levels to 300 m above present levels (figure 11; Siesser and Dingle, 1981). During times when the sea level was significantly lower, rivers flowed across the now-submerged continental shelf off South Africa and Namibia, and diamonds were transported to the then-prevailing beaches. About 25 million years ago, when the sea level was about 500 m lower than it is now, some of these beaches were as much as *several hundred kilometers* into the Atlantic Ocean compared to the position of the present shoreline, because much of the continental shelf was exposed. Littoral drift processes similar to those that operate today distributed diamonds along the ancient coastline. Where the sea level remained constant for some time, wave-cut cliffs and terraces formed, as did sites in which diamonds could be trapped (again, see figure 10). Today, there are at least eight different levels—ranging from 20 to 120 m—below modern sea level, in which persistent wave-cut terraces can be traced over much of the length of the west coast of southern Africa; all potentially hold diamonds.

Beaches that formed when sea levels were higher than today are currently exploited for their diamonds. In Namibia, for example, CDM is presently mining (or has mined) at least four

Figure 8. These two 2.6-ct. diamond octahedra were obtained near the mouth of the Olifants river in 1984. Note their clarity, excellent crystal shape, and the absence of abrasion marks. These diamonds may have traveled more than 1,000 km from their kimberlite source to the sea.

Figure 9. This diagram shows the decrease in the size of diamonds recovered from beach sands from the mouth of the Orange River northward (modified from Sutherland, 1982). The dotted line represents the theoretical decrease in size with distance; the solid line represents the actual distribution pattern. From this it can be seen that the size of diamonds recovered from the sea off Namibia varies with location. (This generalization is not always applicable in South Africa for several reasons, for example, reworking of some deposits by smaller rivers presently crossing the diamondiferous beach sands and terraces.)

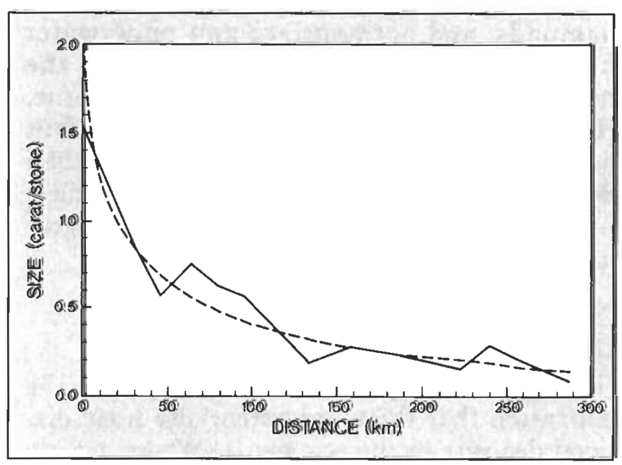

Figure 10. Rich deposits of gem-quality diamonds were concentrated in potholes such as these on a beach terrace at Kleinsee, South Africa, as a result of the relatively high specific gravity of diamonds and their other physical properties (e.g., their durability, which enables them to be transported long distances without being destroyed). Similar potholes and areas of diamond accumulation occur under the sea.

exposed beach levels that extend to 90 m above sea level. In South Africa, in the region between the Orange River and Port Nolloth, diamonds are present in raised beaches at seven elevations ranging from 9 to 84 m (Geological Department, De Beers Consolidated Mines, 1976, p. 27). It was in this coastal area that a 211.3-ct diamond was recovered. The modern beach level and associated terrace is also well mineralized with diamonds, and both surface and underwater mining operations occur from south of the mouth of the Olifants River to north of Luderitz. Thus have sea-level variations and littoral drift distributed diamonds over the continental shelf off the west coast of southern Africa, making it in all probability the greatest resource of gem diamonds in the world.

EXPLORATION, RECOVERY, AND NEW TECHNOLOGY

The captivating questions that follow on the realization that there are potentially huge diamond deposits in the sea are: (1) Where exactly are the diamonds located? and (2) Can they be recovered economically?

The marine deposits can be conveniently divided into two zones on the basis of their depth beneath the water (these zones should not be confused with the A, B, and C zones used in connection with leasing concessions; see figure 3). Those in water shallower than 15 m are being very actively reworked by waves and currents. Those in deeper water are today preserved as "fossilized horizons" (stable locations unaffected by waves and currents). The practical reason for recognizing these two zones is that divers can operate for extended periods of time in shallow water without the need for sophisticated equipment, whereas in deeper water such is not the case.

Since the late 1970s, independent divers have been recovering small volumes of gravel from favored trap sites in shallow water all along the western seaboard of southern Africa (figure 12). In the process, they have demonstrated the presence of rich concentrations of diamonds from the mouth of the Olifants River in the south to Hottentot Bay north of Luderitz. These gravels have been recovered by the divers (figure 13) using suction-pump equipment mounted on tractors on beaches and rocky promontories (figure 14), or on small boats (figure 15). On several

Figure 11. Over the last 70 million years, the sea level off southern Africa has fluctuated from more than 500 m below present levels to more than 300 m above. The dashed portion of the line indicates uncertainty. Modified from Siesser and Dingle (1981).

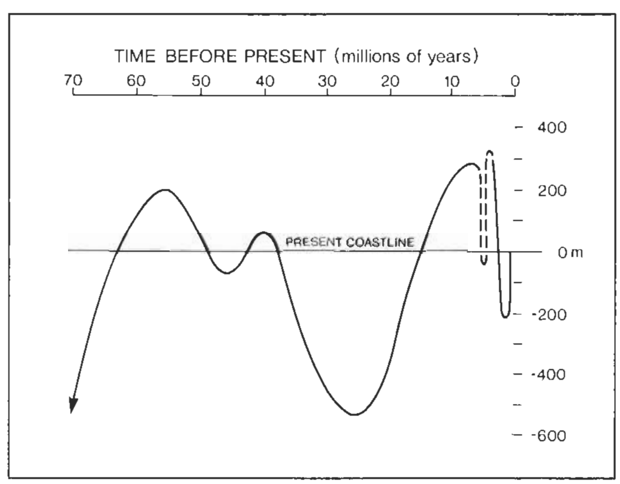

Figure 12. Independent diver Colin Walker enters the ocean to start work in shallow-water concession 12A. Just to the right of this photo, the two diamond octahedra shown in figure 8 were recovered from a cave worn under the cliff.

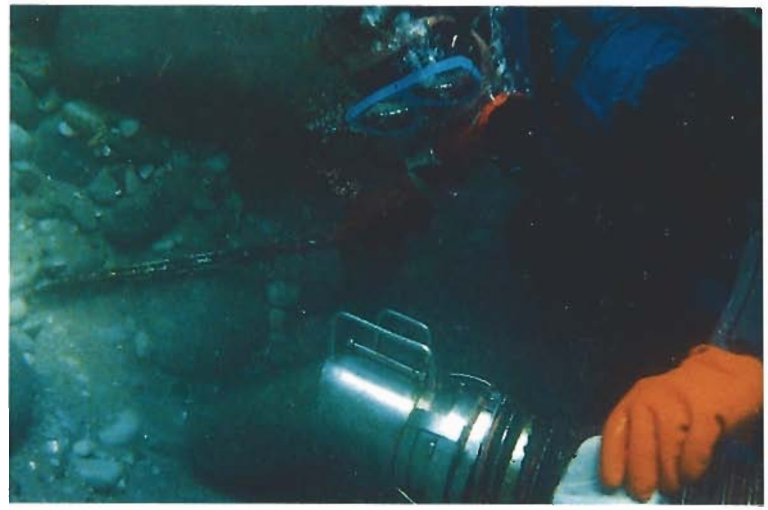

Figure 13. A diver in a heavy-duty wetsuit and 50 kg of lead weights recovers diamonds from gravels in the shallow zones by means of a vacuum hose connected to on-shore suction pumps.

Figure 14. The other end of the suction apparatus illustrated in figure 13 is frequently mounted on a tractor (which supplies the power) that is located nearby (here, far upper right) together with a sieving operation. The sack in the foreground contains diamond-bearing material that has been screened to eliminate the coarse gravel. This "sieved material" will be taken to a diamond-recovery plant for further processing.

Figure 15. The harbor and village of Port Nolloth are home to numerous small boats used in offshore diamond mining. Most of the boats seen here are converted fishing trawlers, each equipped with a decompression chamber as well as with two 20-cm pumps to recover gravel. Divers who work from these boats use gas mixtures and heated diving suits that enable them to dive as deep as 40 m. Most of these boats, as well as the harbor facilities, are owned by Benguela Concessions.

occasions over the past 15 years, individual pump sites have yielded over 1,000 ct of diamonds from less than 10 cubic meters of gravels. Certain individuals have made themselves famous and wealthy by their ability to find these jackpots. Brian MacFarlane, Colin Walker, Jackie Du Toit, Willie Strydom, Davey Clark, and Paul van Gyssen are legendary for their ability to prospect and work the gravels on different parts of the coast.

This level of activity in the shallow zone (<15 m), however, is not likely to flood the world market with diamonds. Even in a record year such as 1990, only 127,000 ct of diamonds were recovered by these methods, and the prospects for improving on this figure are limited.

The real potential lies in the deeper water, where it is possible to explore systematically for the hidden gemstones. For practical purposes, these deeper waters can be divided into two zones (again, not to be confused with the concession zones delineated in figure 3): (a) water depths of 15 to 40 m, in which exploration activities, including sampling, can be carried out with existing technology; and (b) water depths in excess of 40 m, in which more advanced equipment is needed (Benguela Concessions, 1991).

Exploration in these two zones initially takes the form of a geophysical survey that uses sophisticated position-fixing and data-gathering equipment to produce the equivalent of an aerial photograph of the sea floor on which can be superimposed a number of remote-sensing measurements. Such surveys are costly ship-borne operations that are best carried out in good sea conditions.

The amount of detail that can be recorded and interpreted has escalated by leaps and bounds in recent years through computerization of data bases, satellite navigation, and marked improvement in the sensitivity of geophysical equipment. Not only can submerged river channels and deltas, cliff lines, and storm beaches be readily identified, but individual gullies, basin-shaped deposits, and even fossil ripple marks in gravels—the types of features that could contain diamonds—can also be recognized and located again easily.

The next step in the exploration for deep-water deposits is to sample these features to establish whether or not they are mineralized. This can be done in a number of ways. Divers can be used, but at these depths they require expensive diving aids such as decompression chambers, mixed gases, hot-water suits, and ship-to-diver communications. Diving is also a slow procedure. In contrast, devices such as air-lifts, underwater robots, or jet pumps can be custom designed for the job. These can handle much higher volumes of gravel but, unlike a diver, they are not so flexible when it comes to recovering gravel from narrow gullies, geometrically complex potholes, or extensively gullied terrain. Since diamonds often concentrate on such bedrock features in alluvial processes, this is a vital consideration. Recent developments, which include the use of high-pressure water jets to liberate gravel trapped in boulder beds, have shown considerable ability to deal with this problem.

Following exploration and sampling in the deeper-water areas, mining must follow the high-tech route rather than use divers. The west coast of southern Africa has no deep-water harbors other than Cape Town and Luderitz, so ocean-going vessels that can stay at sea for extended periods must be used. Because such boats cannot derive sufficient revenue from the small volumes of gravel recovered by divers, robotics of some sort are mandatory (figure 16). Some of the boats contain full facilities to separate and sort the diamonds.

Figure 16. This is an example of a robotic bottom crawler. It has a suction-type "cutter head" to raise the gravels, as well as cameras for eyes, lights for 24-hour operation, and a 500-m–long umbilical cord to the mother ship. The robot is controlled by an operator on board the ship; divers are used only for inspection purposes and sea-bottom repairs. Such robots can operate 22 hours a day and pump more than 100 cubic meters of suspended solids per hour. This contrasts with the performance of a diver-manipulated pump (see figures 13 and 14), which may produce two or three cubic meters per day in good sea conditions.

CURRENT DIAMOND MINING AND EXPLORATION IN THE SEA

De Beers Marine has been investigating these offshore deposits, and continuously upgrading their activity, for more than 20 years. According to De Beers Consolidated Mines (1990), they currently have in operation four exploration vessels (engaged in prospecting, sampling, and geophysical surveys) and three mining vessels: Louis G. Murray, Coral Sea, and Grand Banks. Clearly, the allocation of such substantial resources indicates a commitment to the recovery of diamonds from the sea based on confidence in the size of the reserves and the technological feasibility of the recovery processes. The current status of the mining of marine diamonds in the territorial waters of Namibia and South Africa follows.

Namibia. After many years of preliminary work, DeBeers Marine (subcontracting to CDM) has begun the trial mining of areas of the sea floor that have been proved to contain significant quantities of diamonds. Custom designed for this purpose, the Louis G. Murray made significant recoveries of diamonds in both 1989 (21,545 ct) and 1990 (29,000 ct), as noted by De Beers Consolidated Mines (Pty) Ltd. (1990 and 1991). At the present time, with two other mining vessels, the Coral Sea and the Grand Banks, De Beers is forming the nucleus of a mining fleet in Namibian waters. This is expected to be a deep-water operation (> 100 m in depth) owing to the fact that some ships (e.g., the Coral Sea) are capable of operating in depths as great as 200 m (De Beers Centenary AG, 1991). In the foreshore (that part of the beach uncovered at low tide), the recent policy of Consolidated Diamond Mines (Pty) Ltd. has been to use massive engineering projects (e.g., "sea walls") that allow temporary reclamation of the surf-zone sea floor for mining purposes or, alternatively, to employ subcontractors who practice the small-scale recovery methods described above.

The Namibian West Coast Diamond Company, based in Luderitz, recovers diamonds from shallow water using shore-pumping units and small boats, and they are actively prospecting in deeper water. They recovered approximately 30,000 ct in 1990. Ocean Diamond Mining Ltd. (ODM) has undertaken extensive prospecting and trial mining within their lease areas over the past decade, with some success. They are currently investigating options to expand the scope of their activities.

No diamond recoveries are being made from other diamond lease areas north of the Orange River at this time. The total amount of marine diamonds recovered in 1990 off Namibia (excluding onshore recoveries) is on the order of 75,000 ct.

South Africa. Today, the interests of De Beers Marine in South African deep-water lease areas are considerably larger than is shown in figure 3, since the company has entered into various agreements with other lease holders, notably Tinto Africa Exploration (RTZ), Three Sea (Pty) Ltd., and Namagroen Eight Sea (Pty) Ltd. De Beers Marine has an extremely active prospecting program based in Cape Town that involves geophysical mapping and sediment sampling. The remaining deep-water concession holders have their own prospecting programs, but they are currently less active. There is no regular diamond production yet from any deep-water areas, but that is expected to change if De Beers Marine is successful in its major sampling effort in the Namaqualand joint venture areas (De Beers Consolidated Mines Ltd., 1991).

There are also prospecting programs in the B concession zones (again, see figure 3), which can have depths greater than 40 m; Benguela Concessions is currently the most active company. Again, mining operations cannot develop further until the technical problems of mining diamonds underwater by mechanical means, such as by use of robotics, airlifts, or other devices, are resolved so that larger-scale recoveries can be achieved. Consequently, there is also little diamond production from mid-water areas at the present time, although sampling has proved that concessions 2(B), 3(B), 4(B), and 5(B) have sites with economic diamondiferous gravels in places.

In contrast, diamonds are actively recovered from all the shallow waters in concessions 1(A)–13(A). Some areas have been more rewarding than others, notably concessions 1(A), 2(A), 5(A), 6(A), and 12(A), whereas no significant quantities of diamonds have been recovered south of 13(A) to this time. In 1990, the combined production of all operating companies reached a record total of approximately 128,000 ct. Conservatively, this production would exceed $23,000,000 in value.

CONCLUSIONS

A unique combination of geologic and geographic (climatic and geomorphologic) factors has resulted in the concentration of an estimated 1.5 billion carats of gem-quality diamonds in the sea off the west coasts of Namibia and South Africa. These factors include: (a) the occurrence of many diamond-bearing kimberlite pipes in the present

Orange River drainage basin; (b) the extensive erosion of these pipes over the last 100 million years; and (c) the consistent drainage of the present and ancestral Orange River westward into the Atlantic Ocean. Wave and wind action, and littoral drift to the north, have resulted in a predictable distribution of diamonds with respect to size. These marine deposits are probably the largest known resource of gem-quality diamonds in the world. However, large-scale recovery of the diamonds from beneath the sea poses major engineering and mining problems. Nevertheless, the prognosis is good for the economic success of the venture, despite the technological challenges, thus ensuring a significant component of the world's future requirements for gem diamonds.

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