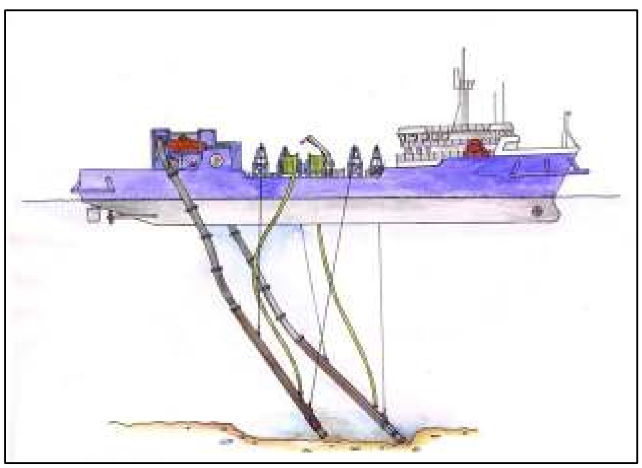
Offshore Diamond Mining

With all the recent interest in diamonds, we decided to reprint this article from March 2002 written by Charlie Heyes of Diamond Fields.

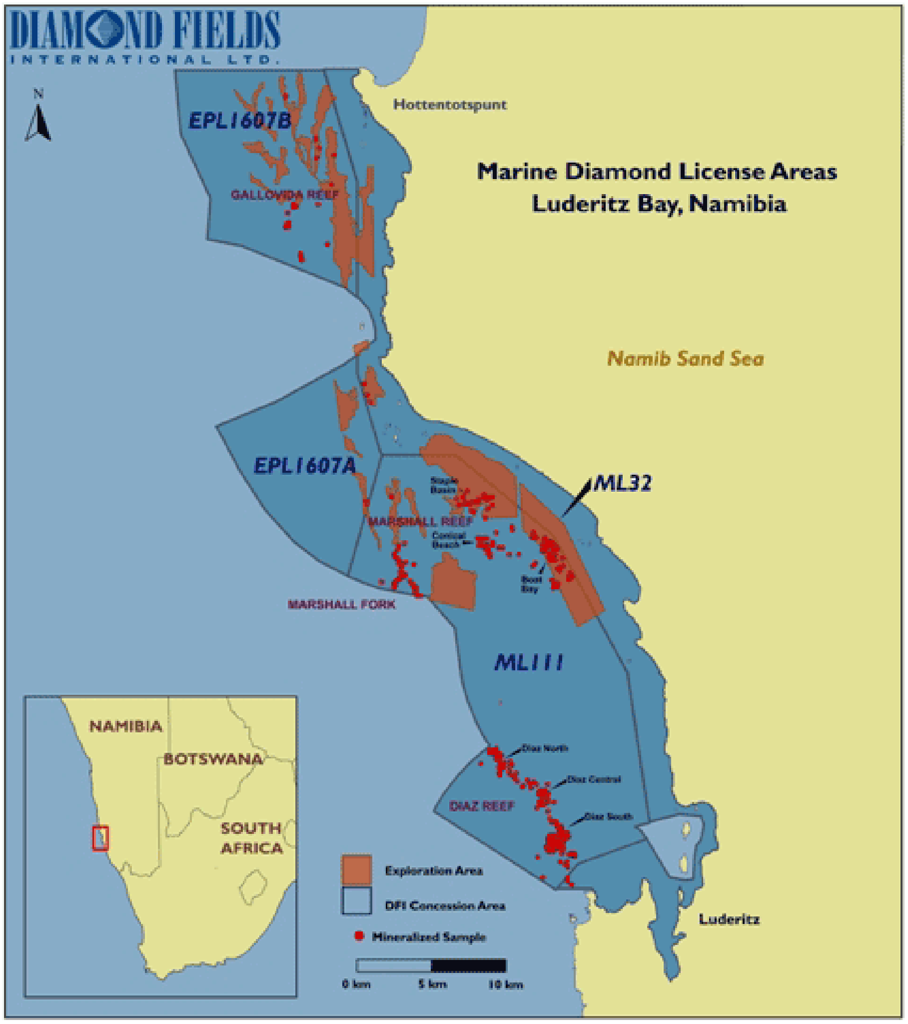
To update the article a little, Diamond Fields International Ltd.'s twin airlift diamond mining vessel *"DF Discoverer"* (ex-Anya, ex-Canmar Supplier V) has resumed offshore mining operations in Namibia on site in the Diaz Reef area in mining licence ML111 offshore Luderitz, Namibia on 19 November 2006 following the recently completed port call for statutory dry docking, repair, maintenance and upgrade programs. Marcon International, Inc. had sold the *"Canmar Supplier V"* in 1994 into this trade. She was since lengthened to 67.9m with the addition of a mid-body section in 1997. Diamond Fields purchased the vessel in 2005. She had has mined the DFI marine concessions in the past under the name *"Anya"*. Past performance of the "Anya" in the Marshall Fork area averaged 2700 carats per month. Following acquisition, the *"DF Discoverer"* was relocated from Luderitz to Cape Town where she underwent an extensive refurbishment, maintenance and repair programme to upgrade the vessel and improve its mining and operating efficiencies. All safety and security systems were reviewed and upgraded. Compressors and generators were overhauled and serviced. Hydraulic systems were completely refurbished. All electrical reticulation was modified, repaired and upgraded. New water makers were installed for improved distribution of fresh water. Sea water distribution for processing was improved. In addition, extensive modification, service, refurbishment and repair work was carried out in the mining and diamond process plant. All pumps and screens in the diamond recovery plant were inspected and replaced where necessary. Following completion of the improvements, the vessel was relocated back to Luderitz to resume diamond production. Photo at right is an assortment of rough diamonds from the DFI Marine concessions in summer 2004.



Twin Airlift System Similar To That Used On *"DF Discoverer"*

Compressed air is pumped into the pipes near the seabed floor creating a vacuum which transports the sediment onto the boat for diamond recovery.

Diamond Fields International in November also reported very encouraging results from the recently completed resource development sampling conducted by Bonaparte Diamond Mines under a joint operations agreement and the expected resumption of mining operations in early November. The sampling program by Bonaparte Bay in the joint operations area in ML111, offshore Luderitz was successfully completed in late October. A total of 291 gem quality diamonds weighing 135.92 carats were recovered and the grid-based sampling results show near-continuous diamond mineralization over a substantial cumulative area of approximately 290,000m2.



A total of 577 grid-based samples were taken of which 159 samples were positive and multiple diamond recoveries (more than 1 stone) were made at 56 sites. Based on groups of closely associated positive results, a total of 9 discrete zones of near continuous mineralization covering a cumulative area of approximately 290,000m2, have been identified.

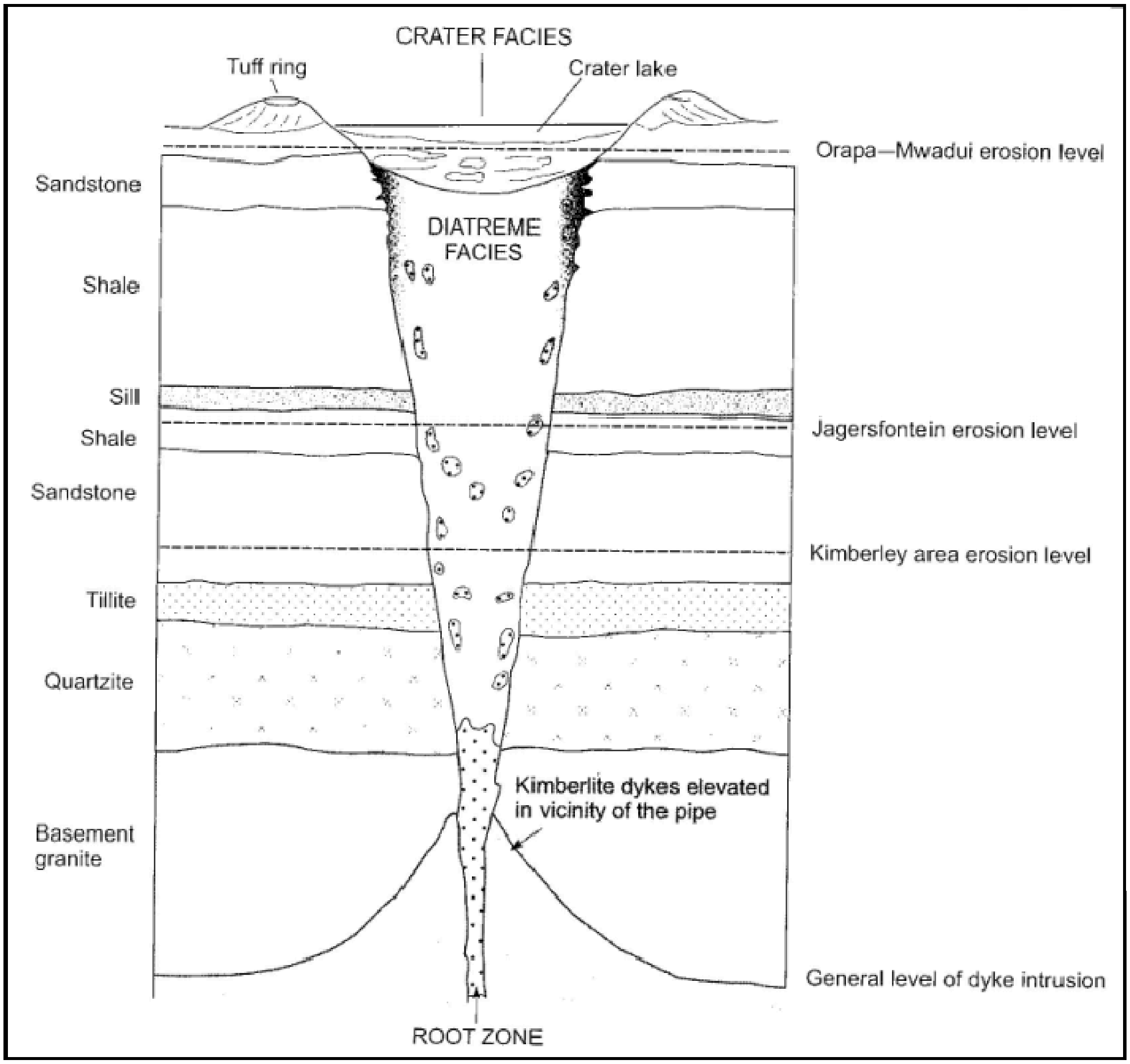
Before considering the present day offshore diamond mining industry, it is useful to first step back and understand the origin of this industry.

Historical Overview

All diamonds are created deep in the earth's crust at very high temperatures and under incredibly high pressure. As magma works its way to the surface through deep fractures it sometimes traps diamonds within it. The magma is very low in silica and after it erupts and cools, it forms Kimberlite or lamprolite rocks. The pipe or dyke represents the conduit that brought the diamonds to the surface. These eruptions were short, but many times more powerful than volcanic eruptions that happen today. The magma in these type of eruptions originated at depths of at least 150 km, three times deeper than the magma source for volcanoes like Mount St. Helens.

Kimberlite pipes are only found in Archean-aged Cratons - areas of rock that are at least 2.5 billion years old. The first kimberlite pipe was discovered on the Kaapvaal Archean-aged Craton near the town of Kimberly, South Africa, hence the name.

Numerous kimberlite pipes have since been found on the Kaapvaal Craton, which extends through parts of South Africa, Botswana and Zimbabwe. The majority of these pipes were formed during two episodes in the Cretaceous Period. The first occurred between 125 and 115 million years ago, the second between 90 and 80 million years ago. The majority of the commercially economic diamond deposits are from the younger period known as the Late Createaceous.



This is a drawing of an idealized kimberlite pipe, the result of a kimberlitic eruption. It illustrates the relative erosional level of three kimberlite provinces in southern Africa. The Kimberley area includes kimberlites emplaced in the Late Createaceous and contain the majority of commercially economic deposits.

From Kimberlites to Sea Diamonds

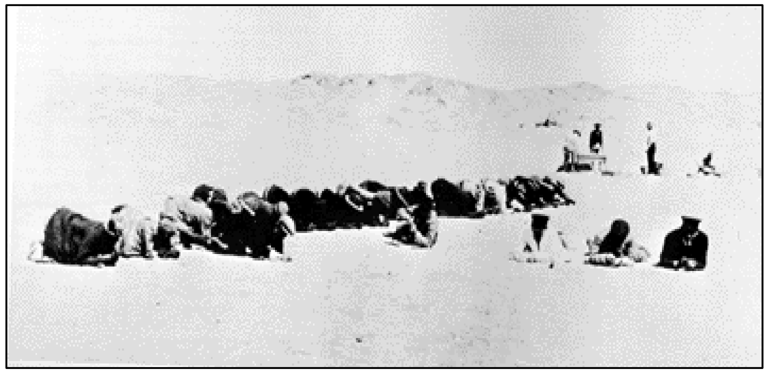
Research has shown that over the past 90 million years most of the drainage basins covering the Kaapvaal Craton have flowed from east to west and emptied into the Atlantic Ocean. This means that weathering, mostly from rain, has eroded diamonds out of kimberlite pipes and swept them into river systems. The diamonds were then carried out onto the delta system when the river meets the ocean. Initially the diamonds were concentrated in small tidal channels on the river delta and in beaches near the delta. They were later redistributed up along the coast of Namibia.

Waves and ocean currents redistribute the diamonds. All of the sediment in the delta, including the diamonds, has been reworked and redistributed through wave action and ocean currents. Over time, wave action moved the diamonds northwards, depositing them in seabed trap sites and beaches along the coast. Since diamonds are heavier then most minerals found in sand and gravel, the continual re-distribution also led to diamond concentration. Because of the weight difference, the diamonds accumulated in low lying depressions while the lighter sand was moved onwards. Over the past 90 million years the sea level has gone up and down many times, adding another level of complexity to the process. These transgressive and regressive cycles resulted in the migration of shorelines of Namibia in a range of up to 100 km. As the sea level goes up, the wave action re-mobilizes the diamonds into new depressions and trap sites and beaches further inland. When the sea level dropped, raised beaches were formed containing diamonds. The picture shows an alluvial mine of an ancient onshore beach terrace. Notice the depth of the sediment in which the diamonds are contained. Also notice the grooves in the bedrock that act as trap sites where diamonds can potentially accumulate

Wind also moved the diamonds. Strong wind currents, originating from the south, also played a role in redistributing diamonds in the beach terraces. Small diamonds, in particular, are affected by eolian or wind erosion as they were swept up distinct channels inshore of the Namibian coast. These wind and water transport mechanisms are still active today, moving diamonds from one resting place to another, creating and destroying deposits, raising and lowering concentration levels. However, since the processes occur over a long time period, it has little affect on the current deposits.

Only the strongest diamonds survive. Diamonds are the hardest substance known to exist, but they are brittle when fractures and inclusions exist in their structure. All of the erosional and weathering processes the diamonds go through cause a great deal of stress on the structure. As a result, many of the imperfect stones are destroyed during their journey from the kimberlite to the ocean. Subsequently, marine diamonds have a remarkable high ratio of gem quality diamonds - as much as 95%. This ratio is much greater than that of land based kimberlite mines, and in general, leads to higher per carat prices obtained from diamonds recovered from the sea.

The mention of diamonds will often bring a sparkle to a person’s eye, especially to that of the fairer sex. Diamond mining is generally associated with an industry centered in the depths of our earth, toiling in dark and humid tunnels, amidst the sounds of continual rock drilling and blasting.



Fewer people realize that the world's largest and most valuable resource of gem quality diamonds lays along the coastal beach areas of Southern Africa and extending offshore, entrapped in ancient submerged beach terraces. Diamonds found their way to this region, having been liberated by erosion over a period of some 100 million years from various volcanic kimberlite pipes, situated in the more central areas of the Southern African Continent and being transported by wind and river systems to their present day settling place. It is estimated that as many as 10 billion carats of diamonds were released in this manner.

Over 90% of the diamonds found in the coastal region are of gem quality, because only the best quality stones survived the harsh transportation process to the coastal areas. It was only back in April 1908 that the first coastal diamond was found, approximately 7km inland, outside the coastal town of Luderitz, Namibia by Zacharias Lewala, a railway worker who was clearing wind blown sand from the local railway line, leading to the port of Luderitz. He showed his find to his supervisor who recognized what the shiny stone might be. Within months and following the news of the diamond discovery, the 'diamond rush' started. Diamonds could be found sitting on the surface of wind blown dunes. By 1930 over 11 million carats of diamonds had been recovered in an area south of Luderitz. Further discoveries were made along the southern coast onshore areas heading south towards Cape Town.

Few people had ventured into the sea itself to continue the search for diamond deposits and it wasn't until the arrival of a Texan entrepreneur by the name of Sam Collins in the early 1960's that marine diamond mining gathered noticeable pace. Exploration of the seafloor revealed that diamond deposits did in fact extend into the sea along submerged ancient beach terraces. Collins founded Marine

Diamond Corp. and mobilized a series of barges equipped with centrifugal and airlift pumping systems recovering diamonds in the shallow waters by De Beers' huge Orange River mouth enterprise. The barges housed processing plants and basic accommodation for the operating crews. The barges were moored with multi point anchoring but struggled with the large South Atlantic swells. More than one barge ended up on desolate beach areas. Some 1.5 million carats were extracted from the sea between 1961 and 1970. Collins alone recovered 380,000 carats in a 15 month period in 1969/70. However, low diamond prices and lack of technology led to a cessation of larger scale marine mining operations in 1970. De Beers, who bought out Sam Collin's operation in 1965, then commenced a period of marine exploration to assess the extent of their marine concession reserves. It was only in the late 1980's that De Beers ventured back into marine mining production and led the way into large scale offshore diamond mining. The industry has since developed into a high technology industry within the marine sector.

Present Day Operations

There are three main areas of offshore mining activity

1. Shallow Water
2. Mid Water
3. Ultra Deep

In the **Shallow Water Concessions,** water depths range out from the beaches to approximately 30m water depth. Small converted fishing boats deploy divers using flexible suction pipes to pump gravels to the surface, where it is sieved and then bagged for onshore processing and hopeful extraction of diamonds. These operations are extremely weather dependant and are often effected by the close proximity to the surf zone and the large Atlantic swells. Security is also difficult to maintain under very basic conditions. Operational time is extremely limited and is usually only for 25% of the year, due to the effects of weather. Some mining is also carried out from the beaches into the surf zone, usually using a tractor mounted gravel pump with a diver pulling out a flexible suction hose. Gravel is then pumped to a small mobile trommel that sieves the gravel to a smaller fraction size. The sieved gravel is bagged and sent for further processing at a central sorting location.

In the **Mid Water Concessions**. Water depths range from approx 30m to 100m. Here the water is generally too deep for cost effective diving and so remote means of dredging is carried out and deployed from larger vessels. The vessels are large enough to carry a dense medium separation (DMS) plant for the onboard treatment of mined gravels and operations continue on a 24 hour basis. Crews remain onboard typically for 28 day or more tours of duty. A variety of mining methods have been developed and will be discussed shortly.

The **Ultra Deep Water Concession** areas stretch out from 100m to beyond 300m water depth. Again the vessels are large self contained vessels deploying remote means of mining, together with onboard processing capability.

Support Vessels & Mining Methods

A variety of mining methods are currently deployed by several of the major operators and concession holders. Whichever mining method is adopted it requires a suitable surface support vessel from which to deploy the chosen mining equipment and that must further act as a floating production platform and hotel for the crew that live temporarily onboard for their period of operational duty.

Shallow Water Mining

Is generally carried out by divers working from converted fishing vessels ranging from 10 – 25m in length. The vessels are either wooden or steel boats and are equipped with a deck mounted gravel pump, feeding into a simple trommel – a rotating sieve screen that separates oversize material from the smaller gravel size, the latter likely to contain marine diamonds. Some of the larger near shore diving vessels are equipped with decompression chambers, the boats operating with crews of up to 10 men onboard. Power for the mining system pump and plant is usually hydraulic via a pump driven by the boats main engine. The divers work on the seafloor using a reinforced plastic suction delivery hose (150mm – 250mm diameter) with a steel diver held digging head. The diver gradually excavates downwards through gravel layers until he reaches the base bedrock layer, here there are gullies that create perfect traps for the diamonds.

The work is intensive and physically demanding when trying to pull the digging head along narrow gullies, while removing larger lumps of weathered and broken rock. Because of the shallow water, the diver is fighting against the effects of swell and working periods are extremely limited because of the prevailing large Southern Atlantic swells. The upwelling Benguela current places cold water along the coast creating further demand on the diver's physical ability. Tailings are dumped overboard or sometimes carried out further offshore in inflatable work boats.

The mining is opportunistic since survey data can be limited due to the proximity to the surf line, preventing use of geophysical site investigation. The boats use GPS (Global Positioning System) navigation to log their positions and in some cases are now using DGPS (Differential GPS) for more accurate recording of mining locations and logging of recovery results. Blowers (Prop wash) are sometimes used to remove deeper layers of overburden that is uneconomical for divers to remove by simple suction pipe alone.

Mid Water Mining and Deep Water Mining

Mining methods in the Mid and Deep Water areas vary but are essentially similar in so much as that they use diver-less mining systems deployed from larger self contained vessels. Prior to mining, these areas are usually extensively surveyed using high-resolution sonar and seismic profiling, coring and bulk sampling.

An accurate profile of the seabed is developed which is then used to plan effective production mining planning. Most mine concession holders contract geophysical site investigation requirements to established marine survey companies who maintain state of the art methodology.

DeBeers Marine have their own dedicated survey department and whereas previously had their own survey vessels, are now chartering and equipping local based vessels for their survey operations. DeBeers Marine has also made significant survey advances in the use of Autonomous Underwater Vehicles (AUV's) for sonar and bathymetry related survey tasks. Bulk sampling is a more difficult process and the majority of concession holders develop their own preferred means of taking bulk quantity samples, ranging from simple airlift devices to complex rotary drilling systems.

There are three main types of mining system currently being deployed in the Mid and Deep Water areas, namely Airlift, Rotary Drill and Crawler based pumping systems. They are all deployed from self contained vessels ranging from 55m – 145m in length. The vessels remain at sea for long periods, some bunkering is carried out whilst remaining on station using ship to ship transfer. The only port calls for some vessels being for emergency breakdowns or for crew change and storing. The vessels are equipped with adequate crew accommodation for 24 hour operations, water making facility using evaporators or reverse osmosis systems, diamond processing plant and final recovery units for the extraction of diamonds. Some vessels are equipped with helicopter landing facilities while others rely on small boat transfer for supplies and crew change. The mining vessels position and move themselves, during mining, on a minimum 4 point anchoring system, with the vessel having to be capable of laying and recovering it's own anchor spread. Navigation and positioning is effected using DGPS (Differential Global Positioning System) and in some cases enhanced to further accuracy using RTK (Real Time Kinematic) positioning systems. More recent innovation has been the inclusion of scanning sonar systems that scan the mining area during operation and are able to produce 3 dimensional imagery of the seabed as it is being mined. Vessels are both chartered and owned by the concession holders. Types of vessel in operation varies depending to a greater extent on the type of mining system being deployed, types include drill ships, construction vessels, offshore supply vessels (AHTS), former dredger and cargo vessels.

The means of pumping material to the surface vessel is achieved using one of two methods namely airlift and centrifugal pumps. The Airlift is the most commonly used pumping system in present use, but the centrifugal pump is also being used and will be described further below and how they are incorporated into the various excavation systems. Both pumping methods have been coupled with the likes of crawler and drill based mining systems as the means of transporting mined material

Airlift

The airlift is the most commonly used pumping means of raising diamond gravel to the surface. The airlift in principal is simply a pipe into which air is injected at the lower end of the pipe, invented around 1797 by Carl Loscher.

The airlift pump is used today in conjunction with a variety of mining methods as the means of transporting the diamondiferous material to the surface. It is also used directly in the form of a simple airlift pipe that is lowered to the seabed and suspended on wires from the surface vessel, feeding material back to the surface via flexible rubber hose. Water depths mined using airlift range from 30m to 200m. Sizes of airlift pipe being used currently range from 400mm diameter to 600mm diameter, larger diameters have been tried but have presented problems in hose handling and the large volumes of air required for driving the system.

The airlift comprises of a suction head, air chamber and pipe tail, the whole assembly being up to 20m in length. The suction head is the “digging end” and is usually a tapered opening with heavy grill to act as an initial material sizing screen and preventing larger lumps of rock from blocking the pipe. The air chamber is situated approximately 2m behind the suction head and forms a chamber where the air is injected into the pipe. On the upper side of the chamber is a long tail of steel pipe that gives added weight and stability to the overall assembly. It also allows a hard piping connection for the air supply since the head end suffers heavy punishment during mining when bouncing into the lower bedrock layers. The ‘mining wires’ running from the surface also attach to lift points at either end of the pipe length.

The designs of air chamber vary from company to company and are often closely guarded, although simple in theory the efficient use of the motive air is essential in gaining maximum flow rate and wastage of air means excessive use of fuel that means higher running/operating cost. The pipe assembly is connected to the surface via lengths of rubber hose of the same internal diameter and that is finally connected to the process plant inlet. Due to the nature of the airlift, inlet velocity of material and water is usually in the order of 5m/sec. As the air rises it expands, the velocity of mixture in the pipe accelerates and could be in the region of 15 – 25m/sec by the time it reaches surface and depending upon water depth being worked.

The big advantage of the airlift pipe is its low capital cost, simple construction, reliability and ability to penetrate narrow gullies where diamonds are known to concentrate. Disadvantages are the low efficiency of the airlift as a means of pumping and the difficulty of achieving fine accuracy since the pipe is suspended from the surface and is effected by pendulum effect and vessel movement.

Centrifugal Pump

The centrifugal pump is also used as a means of pumping material to the surface but to date is not as prevalent as the airlift. The centrifugal pump is usually incorporated into another system and simply provides the transportation for material. Mining is effected using more mechanical means such as a hydraulically controlled arm or rotary drill head. Pumps currently being used range up to suction sizes of 600mm, being driven electrically and in some cases with variable speed control for optimum performance. Pumping efficiency is much higher than with airlift and depending upon the means of agitation can usually provide a higher solids ratio in pumped material. Flow rate is even (4-8m/sec) and so surface exit velocity remains similar to that at inlet, the advantage here is that the process plant inlet design is simpler and cheaper. Pumps can be deployed subsea i.e. onboard a subsea crawler, or housed onboard the surface vessel.

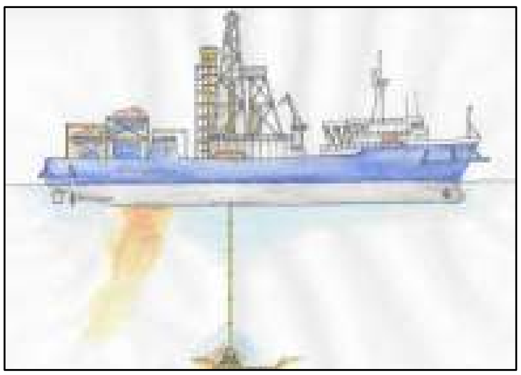
Subsea Crawlers

DeBeers Marine and Namibian Minerals Corporation (Namco) are two large concession holders who have used subsea crawlers for mining operations. The crawler provides a remotely controlled platform/vehicle onto which is fitted a chosen means of mining. DeBeers have used both airlift and centrifugal pumps on their vehicles while Namco has to date used centrifugal pumping alone as the transportation means. Excavation technique varies but includes hydraulically powered digging arms with the suction head situated at the digging end, sometimes assisted with cutter heads or powerful water jetting for additional agitation of the insitu material, suction boxes that are pressed onto the seabed and evacuated through a suction pipe. The variance in seabed conditions influences the type of excavation method used and no one method is the ideal tool, thus the author will not elaborate further in this regard. However the degree of technology used in crawler design is high, they are sophisticated machines incorporating powerful onboard electro/hydraulic systems and complex computerized control systems allowing the operator to work the vehicle from a safe and comfortable control room onboard the surface support vessel and with automated mining functions and monitoring of all vehicle systems. Accuracy of dredging is high since the control of the digging head is independent from the surface effects, the vehicles can be tracked by the latest acoustic beacons and observed on surface sonar arrays. However their support systems are complex and are high capital items, thus running costs are high and the maintenance requirement is demanding. The key to successful operation (besides having diamonds present !) is maintaining high availability of the crawler system, they have higher production capacity to that of the more conventional airlift. The crawlers are designed for continued mining operations and so have to be built ruggedly to withstand the heavy forces exerted on them, typical weights for present units ranges from 120 – 200 tonnes.

Typical oil industry ROV's use lightweight materials etc, but for mining this is not desirable and this is a fundamental difference in the mining type ROV design to that of the smaller oil industry type subsea vehicles. However technological developments made in the offshore oil industry have provided the basis for the equipment now being used on these large mining crawlers and coupled in with dredging technology. Likewise the supporting vessels are comprehensively equipped with heavy and complex launch and recovery systems to be able to handle the crawler mass in sea states generally not below 2m significant swell height. In addition, the vessels have large hose handling and umbilical handling systems being powered from a hydraulic ring main. The crawlers are connected to the surface by their lifting wires, power/control umbilical and larger diameter (up to 600mm id) discharge hoses. Installed power on the crawler can be in excess of 2 megawatts (as with Namco's crawlers) with 50% of this power being used to drive the centrifugal pump alone. Vessels maintain station using four point mooring and slowly track and follow the crawler as it moves along its mining path. A typical daily mined area can be 1000 – 2000 square meters with such mining systems.

Rotary Drilling

Large diameter rotary drills now form the mainstay mining method for DeBeers Marine's offshore mining operations. The drill is coupled with the airlift to provide the means of transportation of mined material to the surface. Drill heads range from 4.5 – 8m in diameter. The system essentially consists of a surface support vessel equipped with a suitably matched drill tower and drill pipe handling system. The large rotary head is attached at the bottom of a string of drill pipe and lowered sequentially by adding sections of drill pipe until it reaches the sea floor. Similar to conventional drill ships the tower is fitted with heave compensation and a gimbal to allow movement of the vessel relative to the drill pipe. A power swivel provides the rotary drilling power at the surface. The drill pipe consists of a main slurry riser pipe (500mm diameter) with smaller air and water jetting pipes running the main pipe sides. Connection is via high tensile pipe flanges. The drill head rotates at a slow speed in the order of 5 rpm and the loading controlled from the drill tower compensation. The seabed material is agitated by the turning drill head, incorporating roller cutters and jetting and the material drawn into a suction inlet and up through the length of drill pipe. Ground is mined by drilling a line of over lapping holes and expanding this on a grid pattern, again the vessel is moved by four point mooring anchor spread. This method of mining has been developed into a reliable and effective mining method, however it is not suitable for all ground conditions and can be hampered by deeper overburden layers.



Vessels

Having described the areas and types of offshore diamond mining system in use, I return to the surface support vessel itself. The offshore mining industry is still a relatively young industry and one who's product remains a luxury item. Capital funding has and still is placed into the concession holders or mining operators preferred means of mining. Thus no company to date has gone to the shipbuilding industry to have a purpose vessel designed and built, instead it is traditional to look for a vessel of opportunity on the used market that best suits ones needs. The size and type of vessel will depend upon the type of mining system to be deployed and space required for the matching process plant etc. The following are typical choices that have been made to date:

Airlift System	AHTS supply vessel
	Suction dredger
	Cargo vessel
Crawler System	Dive/Construction support vessel
	Naval diving vessel
Drill System	Drill vessel
	Cargo vessel

Choice is also market related at the time a purchase is being made. When the oil industry is doing well then supply vessels are often demanding high prices as are drill vessels and vice versa. Having purchased a vessel then the scope for typical conversion to becoming a mining vessel can include the following :

Four Point mooring	Survey and sonar system
Additional accommodation	Additional fuel and water capacity
Process plant	Security systems
Mining system	Hydraulic system
Additional power generation	Helicopter landing facility

It is becoming more common that deck space is increased through the fabrication of side sponsons and also lengthening of the vessel. There are currently four vessels operating that have been widened by the addition of side sponsons. The vessel's draft is also important due to that there are few ports along the western coast of South Africa and Namibia and what there are have limited draft capacity.

Conclusion

While the demand for gem quality diamonds remains, the offshore diamond mining industry will continue to remain in operation and continue looking to improve its methods and efficiency. Although a small market it now offers the shipping and marine industry a chance to promote there services into a very challenging environment and certainly one that will thoroughly test the durability of their product. Those that have been successful usually remain with a good industry name and continue with opportunity for further supply. Thus I hope that this general article will provide ideas and possible opportunity for those who have read this far, in addition to being an article for general interest. Many diamonds have and continue to be recovered by the methods described, but more challenging is that they are only a fraction of what remain underneath the waves. Photo at right is a 5.18 carat diamond recovered in July 2004.