604) Technical Paper-Mining of Diamonds (Chronicle April 2009 issue)

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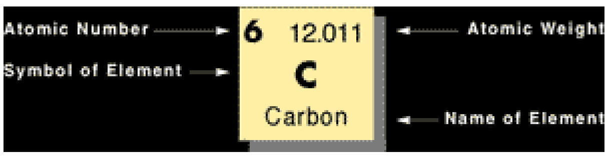
Mining of Diamonds

1. Introduction:

The Greek word "Adamas" meaning unconquerable and indestructible is the root word of diamond. Diamonds have been sought the world over, fought over, worshipped and used to cast love spells

Diamond is carbon in its most concentrated form. Except for trace impurities like boron and nitrogen, diamond is composed solely of carbon, the chemical element that is fundamental to all life.



But diamond is distinctly different from its close cousins the common mineral graphite and lonsdaleite, both of which are also composed of carbon. Why is diamond the hardest surface known while graphite is exceedingly soft? Why is diamond transparent while graphite is opaque and metallic black? What is it that makes diamond so unique?

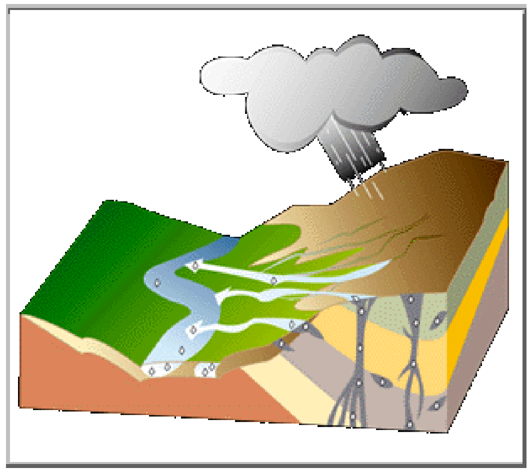
The key to these questions lie in diamond's particular arrangement of carbon atoms or its *crystal structure*--the feature that defines any mineral's fundamental properties. A **crystal** is a solid body formed from the bonding of atomic elements or compounds in a repeating arrangement. Often, crystals possess smooth external faces. Due to their symmetrical and finite nature, the building blocks of crystals are limited to relatively small numbers of atoms, and their chemical compositions to simple numerical combinations of elements.

All diamonds are at least 990,000,000 years old. Many are 3.2 billion years old

2. Formation:

Geologic processes create two basic types of diamond deposits, referred to as primary and secondary sources. Primary sources are the kimberlite and lamproite pipes that raise diamonds from Earth's mantle, where they originate. Secondary sources, created by erosion, include such deposits as surface scatterings around a pipe, concentrations in river channels, and fluxes from rivers moved by wave action along ocean coasts, past and present. Mining of these deposits depends upon sufficient concentration and quality of diamonds.

This diagram shows the trail of diamonds left by geological processes. The primary deposits, or diamond pipes, are the vertical portion. The flared top of the pipes can yield substantial quantities of diamonds, but following the narrowing pipe downward eventually becomes unprofitable. Note how erosion of the landscape moves surface minerals -- including the diamonds -- from the pipes down hills, streams, and rivers to their ultimate destination, the ocean. Because diamonds are dense they concentrate at the bottom of active zones of moving sand and gravel. Secondary deposits may be found far from active means of transport, in the fossilized channels of now-vanished rivers or under fossil beaches.



3. Discovery:

The first river-bed (alluvial) diamonds were probably discovered in India, in around 800 B.C. The volcanic source of these diamonds was never discovered, but the alluvial deposits were rich enough to supply most of the world's diamonds until the eighteenth century, when dwindling Indian supplies probably spurred the exploration that led to the discovery of diamonds in Brazil, which became the next important diamond source. Beginning in l866, South Africa's massive diamond deposits were discovered, and a world-wide diamond rush was on. The South African diamond output was unraveled until major deposits were found in Siberian permafrost in l954. And currently Western Canada is the site of the world's newest diamond rush.

Throughout much of history, diamonds were mined from the sand and gravel surrounding rivers. But in South Africa in 1870 diamond was found in the earth far from a river source, and the practice of dry-digging for diamonds was born. More sophisticated mining techniques allowed deeper subterranean digging, as well as more efficient river (and, most recently, marine) mining, than ever before.

4. Mining of Diamonds:

4.1. **Alluvial mining:** Alluvial mining extracts diamonds from sand, gravel and clay using the open-pit method. The process involves removing the overlying barren ground, digging up the bearing ground, and then extracting the diamonds.

4.1.1. Overburden removal: The first step in the mining process is to remove the overburden – the surface material covering the diamonds. This can be anything up to 40m thick and can vary from loose sand to cemented conglomerate.

Various methods and equipment are used for this process:

* Conventional stripping using bowl scrapers and bulldozers, although flexible, it is a costly system

* ADT stripping uses excavators and articulated dump trucks (ADTs) and is flexible and cost-effective

* Stripping by bucket-wheel excavator

* Stripping by dragline, although the lowest-cost stripping method, reduces flexibility as the dragline is cumbersome

4.1.2. Ore excavation and bedrock cleaning: Most of the ore is excavated by trackdozers and excavators. They create windows from which front-end loaders remove ground and place into ADTs and haultrucks. The bedrock is then cleaned by employees using pneumatic breakers and a containerised vacuum cleaning system. In areas where cemented conglomerates occur, it is necessary to drill and blast.

For lightly cemented areas, we use hydraulic impact hammers to separate the diamond-bearing material from the bedrock, or we use the trackdozers' ripping tool to break it up.

Once excavated, the ore is transported to ore processing plants where it is crushed to pieces smaller than 150mm. A process of dense medium separation, using ferrosilicon as the medium, produces a diamond-rich concentrate from the crushed gravel.

The final concentrate represents around 1% of the material originally fed to the plant. The concentrate is sent to a central recovery plant, which produces the final 100% diamond product.

4.1.3. Dewatering: As alluvial mining takes place close to rivers and/or the ocean, water has to be drained from the working area. For instance, beach walls help us to mine the area between the original sea low-water mark and the original high-water mark.

These walls prevent wave erosion and are created and maintained by dumping overburden sand onto a wall and then pushing it out to sea with trackdozers. Mining now takes places some 300m beyond the original high-water mark and 19m below mean sea-level.

In areas where the water table is above the diamondiferous horizon, we install a system of well points along the landward side of the beach wall. This stabilises the wall and reduces seepage into the working area.

Further dewatering is carried out by conventional pumps and this allows the mining operations to proceed below sea-level.

4.2. **Marine mining:** Marine mining extracts diamonds from the seabed. Methods vary from shore-diving to specialised ships, each of which is, in effect, a mine.

Two mining methods are used:

Horizontal system: a seabed crawler brings diamond-bearing gravels to the vessel through flexible slurry hoses.

Vertical system: a large-diameter drilling device mounted on a compensated steel pipe drill string, recovers diamond-bearing gravels from the seabed following a systematic pattern over the mining block.

Namibia has the richest known marine diamond deposits in the world, estimated at over 80 million carats - all of these deposits originally coming from kimberlites in South Africa.

They were washed down the Orange River and deposited at the river mouth as well as along the coastlines of Namibia and South Africa.

Debmar Atlantic 2: One of the ships used in Marine mining by DeBeers

4.3. **Open-pit mining:** Diamonds can be found in volcanic pipes filled with a blue rock called kimberlite. Mining of the diamond-bearing pipe starts with the excavation of a pit into the pipe. In this process, called "open-pit" or "open-cast" mining, the initially loose and eventually hard ore material is removed with large hydraulic shovels and ore trucks. Hard rock is drilled and blasted with explosives so the broken material can be removed.

Venetia Mine: currently the largest producer of diamonds in South Africa.

Open-pit mining is used when diamond deposits appear on or near the surface. The overburden, or surface material covering the diamond deposit (or ore body), is relatively thin and unsuitable for tunnelling (as would be the case for sand, cinder, and gravel).

Open-pit mining generally:

* Generates revenue quite early

* Results in a flexible mining rate and sequence

* Has a lower initial capital and operating cost per tonne mined

* Allows larger machinery to be used

* Leads to better blending capabilities

The size, shape and value of the deposit, as well as the stability of the host rock, determine the layout and ultimate depth of the open-pit mine.

This method uses GPS and dispatch type control systems, and integrates this with on-line drilling systems and blast design, to make the mining operations as efficient as possible.

When the open pit is deep enough, mining goes underground with vertical shafts that descend into horizontal drifts, or passageways, that enter the pipe.

4.4. **Underground mining:** Underground mining is used to extract diamonds from kimberlite pipes that occur below ground.There are numerous methods of underground mining, but mechanised blast hole open stopping (BHOS) is the most often used.

One of the main advantages of BHOS is that it allows a mine to be converted from open-pit to underground because it:

* Is able to build tonnage and can easily interface with open-pit layout

* Does not require major upfront capital, but does require high long-term development cost

* Can selectively mine waste

* Is less dependent on the predictability of the rock mass

In BHOS mining, long hole drilling rigs are used to drill rings of holes from drill drives situated perpendicular to the pit faces. These holes are then charged and blasted and the broken ore is loaded by load-haul-dump units (LHDs).

BHOS cannot be used too deeply when kimberlite pipes are situated in unstable country rock such as the Karoo System as it vulnerable to waste dilution. Where this occurs the mining method is changed to **modified sub-level caving.**

The underground infrastructure (tunnels, level spacing, etc) remains largely unchanged, but the amount of material extracted is reduced to facilitate semi-choke blasting. The broken ore is then loaded via the tunnels by LHDs. This creates a layer of ore above the retreating tunnels that protects against waste ingress with the loaded ore.

This method reduces the amount of ore that can be extracted as some is left behind in the protective layer. It is, therefore, an interim method which is used while the infrastructure for a block cave is being established.

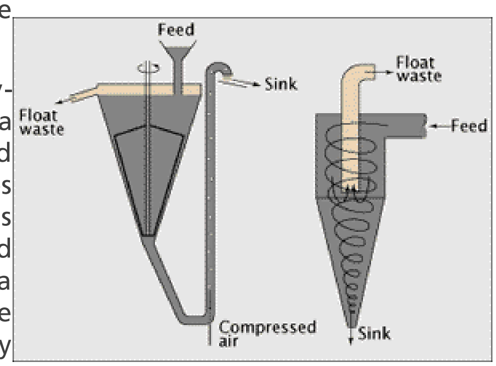
Block caving is the most cost-effective and productive method of mining kimberlite underground. It does depend, though, on the pipe having sufficient cross-sectional area to allow the ore to cave, once it has been undercut.

5. Processing of Diamonds:

Once a mining operation yields ore, the diamonds must be sorted from the other materials. This process relies primarily on diamond's high density. An old but effective method is to use a washing pan, which forces heavy minerals like diamond to the bottom and waste to the top. Cones and cyclones use swirling heavy fluids mixed with crushed ore to achieve density separations. With 99 percent of the waste in the ore removed, further separations may use either a grease table or an x-ray separator. Final separation and sorting is done by eye.

Crushed ore is mixed with a muddy water suspension, called puddle, and all is stirred by angled rotating blades in the circular washing pan. Heavier minerals settle to the bottom and are pushed toward an exit point, while lighter waste rises to the top and overflows as a separate stream of material.

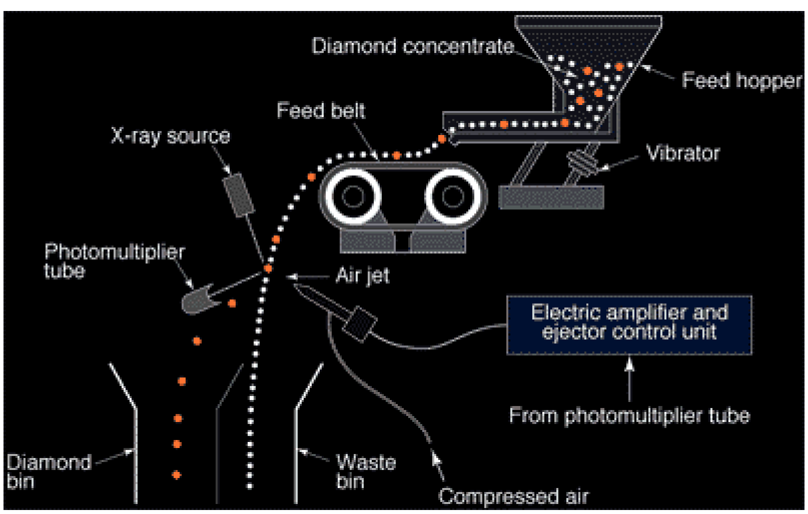
The surface of diamond is highly unusual in that it resists being wetted by water but sticks readily to grease. Here, wet gravel washes across 3 inclined surfaces covered with beeswax and paraffin. Diamonds stick to the grease while wetted waste minerals flow past. The operator routinely scrapes the material that adheres to the table into a grease pot, using a trowel. The grease in the pot is melted and the diamonds are removed in a strainer. More automated systems use a rotating grease belt and scraper.



This diagram shows how cones (left) and cyclones (right) use heavy-media separation. Diamond-bearing concentrate is mixed with a fluid near the density of diamond. Separation occurs in cones and cyclones by swirling the mixture at low and high velocities respectively. In the cone, rotational mixing permits lighter minerals to float to the top and run out as overflow, while diamonds and dense minerals sink to the bottom and are sucked out with a compressed air siphon. In the cyclone, fast rotation of the suspension drives heavy minerals to the conical wall, where they sink to the bottom and are extracted, while float waste minerals are sucked from the center of the vortex. Cyclones are about 99.999% efficient at concentrating diamonds and similarly dense minerals from the original ore.

The x-ray separator system acts on a thin stream of particles from the concentrate accelerated off a moving belt into the air, where they encounter an intense beam of x-rays. Any diamond fluoresces in the x-rays, activating a

photomultiplier that triggers a jet of air, deflecting the diamonds (red) into a collector bin.



6. **Famous Diamonds:** Famous diamonds often have complex and even controversial histories because of the secrecy surrounding such stones

6.1. **The Star of Africa:** At 530.20 carats the Cullinan I or Star Africa diamond is the largest cut diamond in the world. Pear-shaped, with 74 facets, it is set in the Royal Scepter (kept with the other Crown Jewels in the Tower of London). It was cut from the 3,106-carat Cullinan, the largest diamond crystal ever found. The Cullinan was discovered in Transvaal, South Africa in l095 on an inspection tour of the Premier Mine.

The Cullinan was cut by Joseph Asscher and Company of Amsterdam, who examined the enormous crystal for around six months before determining how to divide it. It eventually yielded nine major, and 96 smaller brilliant-cut stones. When the Cullinan was first discovered, certain signs suggested that it may have been part of a much larger crystal. But no discovery of the "missing half" has ever been authenticated.

6.2. **The Excelsior:** Probably the second largest stone ever found (if the lost Braganza cannot be found and authenticated). A high-clarity, blue-white stone, it was found in l893 by a South African mine worker who picked it out of a shovelful of gravel. Because of its irregular shape, it was cut into 21 polished stones, of which the largest was a marquise of 69.80 carats. A smaller, 18-carat marquise stone cut from the Excelsior was displayed at the 1939 World's Fair by De Beers.

6.3. **The Great Mogul:** The world's third largest gem-quality diamond was named after Shah Jehan. It was found in the mid-seventeenth century in Hyderabad, India. Its whereabouts are not presently known, and it may no longer exist as a single large stone e. It has been confused with several other famous diamonds, most importantly the Orloff, which has also been described as a faintly blue rose-cut stone. It is said that the stone was so badly cut that the lapidary, instead of being paid by the Shah, was forced to pay a heavy fine. When Tavernier so the Mogul, he described it as looking like an egg, and weighing 280 old carats.

6.4. **The Darya-I-Noor:** The Darya-I-Noor is a flawless, transparent pink stone, estimated at 175 to 195 carats. It is the largest and most remarkable gem in the Crown Jewels of Iran, and was one of the spoils of Persia's attack on Delhi in l739. It is now set in a gold frame with other diamonds, topped by a crown bearing lions with ruby eyes, holding scimitars. It was worn by the last Shah for his coronation in l967.

6.5. **The Koh-I-Noor:** The name of this diamond means "Mountain of Light" and its history, dating back to1304, is the longest of all famous diamonds. It was captured by the Rajahs of Malwa in the sixteenth century by the Mogul, Sultan Babur and remained in the possession of later Mogul emperors. It may have been set in the famous Peacock Throne made for Shah Jehan. After the break-up of the Persian Empire the diamond found its way to India. It may have traveled to Afghanistan with a bodyguard of Nadir Shah, who fled with the stone when the Shah was murdered, to be later offered to Ranjit Singh of the Punjab in exchange for military help (which was never delivered). After fighting broke out between the Sikhs and the British, The East India Company claimed the diamond as a partial indemnity, and then presented it to Queen Victoria in 1850. When the stone came from India, it weighed l986 carats; it was later recut to l08.93 carats. It was first worn by the Queen in a brooch. It was later set in the State Crown, worn by Queen Alexandra and Queen Mary, and 1937 was worn for by Queen Elizabeth for her coronation. It is kept in the Tower of London, with the other Crown Jewels.
