Kimberley: Diamond City

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Kimberley exists because of its diamonds. It is the home of the world's largest hand excavation on one of a cluster of kimberlite pipes, which are now mined deep underground and are also the source of vast alluvial diamond deposits.

The veldt of southern Africa's interior is a vast, semi-arid plateau. The Orange and Vaal Rivers rise on the Drakensburg Mountains, and then meander lazily across the open plains to the Atlantic (Fig. 1). A cover of Karoo rocks, up to 1000 m thick, lies almost horizontally and undisturbed, even though they are of Carboniferous to Jurassic age. There is minimal younger sediment, but there is just enough weathering and soil cover to obscure large areas of the bedrock geology. Basement is exposed in many inliers, and is dominated by the ancient Kalahari craton, bounded by Precambrian foldbelts, all truncated by the Karoo unconformity (Fig. 2).

In 1866, the heart of the veldt was occupied by a scatter of native peoples and a few early farmers of Dutch and British origins; its land could support no more. On a farm near Hopetown, beside the Orange River, the Jacobs children were playing the old game of 'five stones' with pebbles that they had picked up. One stone, about 13 mm in diameter, looked unusual, and a neighbouring farmer, Van Niekerk, took it away. It spent four months in various pockets, went unsealed through the mail and was dropped in thick grass before it was identified as a 21-carat (4.2-g) yellow diamond.

In those days, the world's diamonds came from India, and the discovery was ignored – until the next diamond was found, and was immediately recognized. This was a stone of 83 carats, just over 20 mm across, found by a shepherd boy in November 1868, again on the banks of the Orange River. In a hasty deal, he sold it to Van Niekerk, for 500 sheep, 10 cows and a horse; it became known as 'The Star of Africa', and the stone cut from it changed hands in 1974 for £225 000. This diamond started a rush, and by 1870 there were 10 000 miners working the 'river diggings' along the alluvial tracts of the Orange and Vaal Rivers. It was then considered that diamonds were found only in alluvial placer deposits, so there was little incentive to wander into the dry veldt away from the comforts of the river.

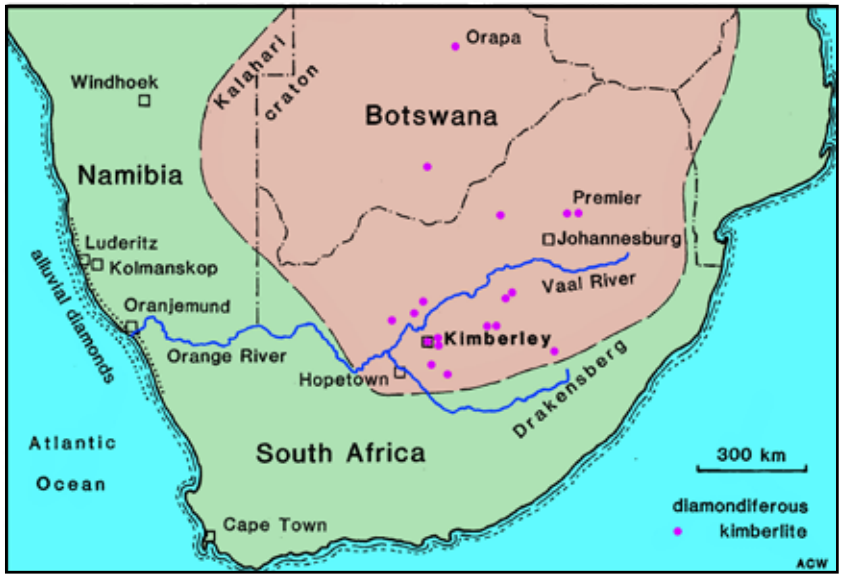


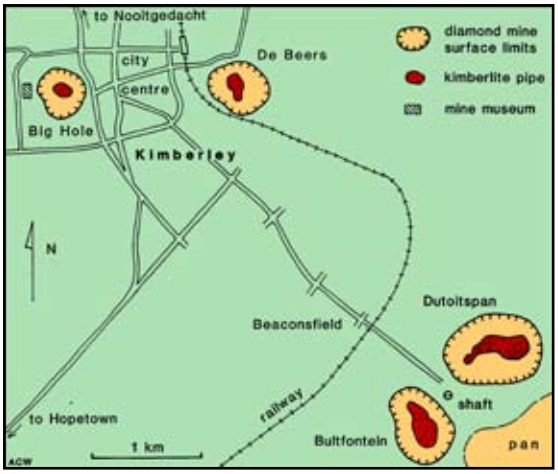
Fig. 2. Diamond-related localities in southern Africa. Some of the kimberlite symbols represent groups of pipes, and not all of the pipes are rich enough to be mined.

Fig. 1. The Orange River, perhaps the world's largest conveyer of diamonds.

Late in 1868, diamonds were also picked up by a farmer's wife on land that they had bought near a brackish pan from Abraham du Toit, and this was 30 km from the Vaal River. A hut on the farm was found to have 17 diamonds within the mud blocks of which it was made. There was soon a rush of miners who started to work these 'dry diggings' at Dutoitspan, where the diamonds were assumed to lie in remnants of river gravel terraces. By looking around they found diamonds in two more patches. On the Bultfontein farm, 269 loose diamonds were picked up on the surface without using a spade. The third patch was on a farm owned by two brothers named De Beer. Also on the De Beers farm there was a small hill, which was named Colesberg Kopje in July 1871, when it too was found to yield diamonds.

Each find had prompted an influx of miners, but this little hill was the richest of all. Miners

flocked in from the other dry diggings, from the river diggings and from further afield; many newcomers travelled across empty wilderness for a month to reach the diamond fields from the coast. The camp which grew around the hill became known as New Rush. The ground was divided into more than 1500 claims, and there were over 2000 miners working there by the end of 1871. The real truth of the diamonds was only revealed when the miners dug right down through the diamond-bearing soils until they hit rockhead – and then found that the diamonds continued on down within the rock. The dry diggings were not in placer deposits but were in the weathered tops of diamond-bearing kimberlite pipes. The rock did not yet have its name; it was later christened after the town of Kimberley. The town was only established in 1873 to encompass the mining camps around all the dry diggings on the cluster of four diamondiferous pipes (Fig. 3). A fifth pipe, Wesselton, lay 4 km away and was prospected back in 1871, but was only developed by a rush of miners in 1891.



The Big Hole

At the richest of the diggings, the hill of Colesberg Kopje soon disappeared, while the pipe below it became known as the Kimberley pipe. Mining claims were each just under 10 m square, and were staked out in a regular pattern between 14 straight and narrow streets, each about 200 m long, which reached across the entire diggings on the oval pipe outcrop. On each claim the ground was lowered as fast as its owner could work, and by mid-1872, some claims were reached only by ladders, because they were 10 or 15 m above or below their neighbours. Soon the unmined streets started to collapse, and the first ropeways were installed from claims up to sites on the rim of the communally deepening open mine. By 1874 the mine was shrouded in a spider's web of ropeways – providing one of the world's great visual images of mining (Fig. 4). Later in the same year, the first of the great landslips occurred as the unsupported walls in the soft shale country rock slumped into the pipe diggings.

Fig. 4. One of the classic views of the Kimberley pipe diggings in 1874, when the ground was most deeply stepped across the different claims and the web of ropeways was at its thickest. (Photo by C. Evans, courtesy of Kimberley Africana Library.)

Fig. 3. (left) The cluster of four kimberlite pipes lying within the city of Kimberley. Outlines of the kimberlite pipes are shown at the level of the base of the Karoo.

Uncontrolled deep diggings were clearly leading to new problems, only matched by increasing problems with marketing this vast new output of gemstones. Mergers and buyouts had to be the way forward, and two Englishmen, Barney Barnato and Cecil Rhodes, emerged as the entrepeneurs of the day. In March 1888, De Beers Consolidated Mines was formed, and by 1890 it owned all the diamond mines. At the same time the landslides into the open mine were becoming worse, but the way was now open for the transfer to underground mining. A deep main shaft was opened in 1892, and within a few years open-pit mining of the Kimberley pipe had ceased.

The Big Hole is what remains open to daylight on the Kimberley pipe. It is the largest hand-dug excavation in the world. The diamond diggings were only over the outcrop of the pipe, which formed an oval 300 m by 180 m. Massive landsliding of the upper parts of the pipe walls then gave the Big Hole the flare to its present surface width of nearly 500 m. The open diggings reached a depth of 240 m, to produce 8 million tonnes of kimberlite. Beneath them, the underground mine worked another 700 m down the tapering pipe, until mining ceased in 1914, having produced another 14.5 million tonnes of kimberlite. With a total yield of just over 2.7 tonnes of diamonds, this represents little more than 0.1 parts per million.

Kimberlite pipes

Perhaps best described as a serpentinized mica peridotite, kimberlite is an unusual rock. Most

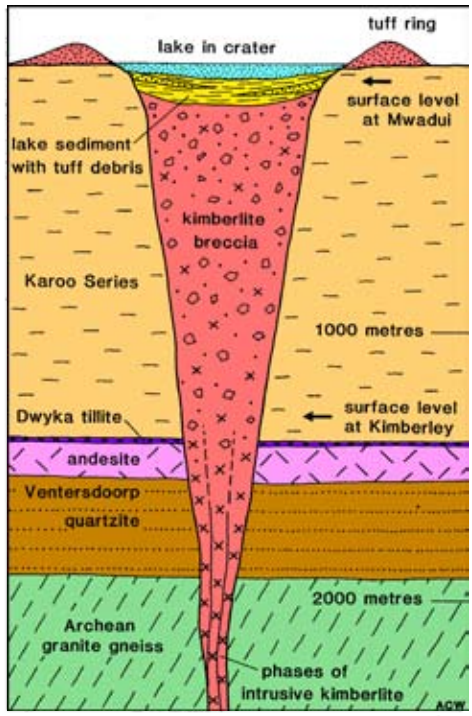


Fig. 5. Profile through a typical kimberlite pipe in the Kalahari craton.

of its original olivine has been altered to serpentine and talc, with ilmenite as a by-product; phlogopite mica and calcite are also major components. Pyrope garnet is usually present, and diamond occurs in just some kimberlites. Part of this suite of minerals formed at high pressures, which indicate origins of the magma at depths of 100–250 km, within the upper mantle.

Nearly all kimberlite is found in vertical pipes, which occur in all the shield areas of the world. Enough pipes have now been exposed by deep mining to recognize their characteristic form (Fig. 5). The model pipe is less than 100 m in diameter in its root zone, but its uppermost 2000 m flares out to reach diameters of 1000–1500 m. This is the diatreme zone where the release of pressure allowed expansion of steam and carbon dioxide in the magma, increasing its mobility and also causing the serpentinization of the olivine. On top of the diatreme, the magmatic volatiles created an explosion crater, with tuff rings around a vent that was backfilled with fluidized debris. These kimberlite breccias contain up to 25% of xenoliths of igneous rocks and sandstone, which have been matched with their wallrock sources to indicate their vertical displacement by 500 m or so, either upwards or downwards within the diatreme. The early explosive phase of the pipe appears to have been followed by periods of quieter upwelling of magma; each pipe has multiple phases of kimberlite intrusion, each with its own characteristic diamond content. Except where crater fills of lake sediments survive, the top 15–25 m of kimberlite is normally weathered to 'yellow ground', and this grades down into fresh 'blue ground', distinguished by the blue–green colours of its hydrated iron silicates.

Most of the African kimberlite pipes formed in the Cretaceous, but they range from Precambrian to late Tertiary. Age is significant because it determines the level of erosion on the pipes. The Cretaceous pipes around Kimberley are all eroded to well down in their diatreme zone, but others are not. Tanzania's Mwadui pipe, found by the geologist John Williamson in 1940, still has much of its crater zone; it is 1600 m across and has lake sediments 200 m deep on top of the main kimberlite, which tapers to 600 m across at a depth of 500 m. The Orapa pipe, found in Botswana in 1967 after 12 years searching on a follow-up to the discovery of just three placer diamonds, is also so large and rich because its crater zone has not been eroded away. All kimberlite pipes have increasing diamond contents in their highest sections, suggesting that the diamonds were easily mobilized in the gas-rich eruptions.

The distribution of kimberlite pipes is very uneven through the world's shield blocks, as there is definite clustering. More than 50 pipes lie around Kimberley, although only seven have been mined for their diamonds. Very few of the kimberlite pipes actually contain diamonds, and even fewer are worth mining; Namibia has 25 pipes, none of which is diamondiferous. Within the known groups, pipes are commonly aligned, perhaps due to emergence of the volatile magma up very deep-seated fractures. Kimberlite is also found in dykes; these are generally less than a metre wide, but outcrops extend for many kilometres and they have been mined to depths of 600 m. There is no clear relationship between the pipes and the dykes.

Until the Kimberley discoveries in the 1870 s, the world supply of diamonds was mainly from alluvial sources in India. From then on, the remarkable concentration of pipes in the Kalahari craton let southern Africa dominate the diamond supply for over a century. The Botswana discoveries in the 1960s continued the tradition. Subsequently, the great diamond pipes of Siberia's Yakuta region started to change the world resource patterns, and Australia has become the largest single producer since 1986. Through all this, Africa continues to provide about half the world supply, and also yields more than its share of large, top-quality gemstones.

The underground mines

There are five pipes still being mined in the Kimberley region. These include two of the original discovery sites which lie within the city limits; the Dutoitspan and Bultfontein pipes

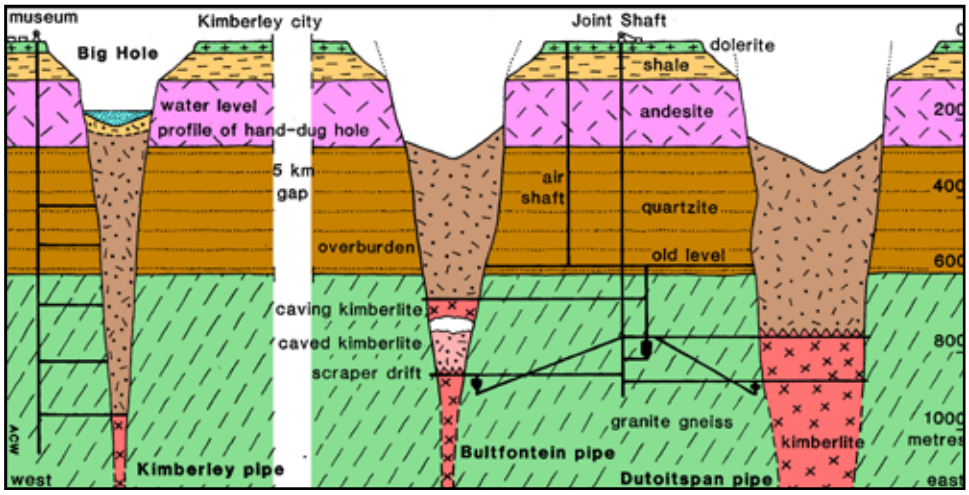


Fig. 6. Simplified profile through three of the mined pipes at Kimberley. Only a few of the mine workings are shown, and the Dwyka tillite is too thin to mark at the base of the Karoo shale. The Dutoitspan pipe is much thinner in the north–south direction.

are so close to each other that they are worked by a common deep shaft system. Like the Big Hole on the Kimberley pipe, these both started as surface mines, but then had to convert to underground working.

The main method of modern mining is block caving, of which the development at Bultfontein is a fine example (Fig. 6). From the joint shaft in country rock, a level at 860 m below ground leads to a loop tunnel around the pipe, also cut in the country rock, which is granitic gneiss at this depth. Inside the loop, twelve parallel scraper drifts cut clean across the pipe at 14-m intervals, and these all have thick concrete linings. Drawpoints pierce the concrete sidewalls of the drifts at 5-m intervals (Fig. 7), and, from these, cones of the kimberlite are drilled and blasted out to a height of 10 m above the drifts. Where the cones coalesce, a complete horizontal slice across the pipe is blasted out. The undercut kimberlite then caves and collapses under its own weight, and the broken ground falls through the drawpoints into the scraper drift. Within the drifts, the rock is scraped out, dropped into rail trucks and hauled to the underground crusher, before being lifted to the surface in the shaft skips.

Fig. 7. Looking through a drawpoint in a scraper drift at the 860-m level in the Bultfontein mine. Beyond the concrete arch, the kimberlite blocks are temporarily jammed at the base of a huge pile of broken rock. The tyre and chain prevent the blocks running into the drift while maintainance work is carried out on its concrete lining.

Fragmentation and caving of the weak kimberlite is aided by long blast-holes drilled from levels above the scraper drifts. These ensure a continuous flow of broken rock, and about 180 m of the pipe is dropped into one level of scraper drifts before the operation is repeated at a lower level. Surface debris, tipped minewaste and collapsed barren wallrock form a cap which is left on top of the caving kimberlite. The bulking of the broken rock and the taper on the pipe increase the height of this debris cap, so that the collapse crater at the surface is only a few hundred metres deep.

After hoisting to daylight, the kimberlite is crushed to a maximum size of 32 mm. As diamond has a relative density of 3.5, the main separation is by washing and cycloning in heavy fluids. The dense fraction of the coarse material is then cascaded through an X-ray beam; in this the diamonds fluoresce, and a photo-electric detector directs an air jet to blow the individual diamonds into a collector box away from the waste material. These days, only the fine fraction of the heavy minerals is treated on grease belts, to which the diamonds adhere. The gem diamonds are then sent, together with most of Africa's mine output, to Harry Oppenheimer House in downtown Kimberley, for sorting and valuation. This is all done by hand under indirect sunlight, on benches in front of large south-facing windows; the distictive high-rise building was built solely for this critical task. All sales of the rough stones are in London, before they go for cutting, mainly in India, Israel, Belgium and the USA.

Kimberley today

Any travelling geologist in southern Africa should take in a visit to Kimberley, because there is nothing else quite like it. The Big Hole on the Kimberley pipe is now within an excellent museum complex which recreates some of the atmosphere of the diamond camp of the last century. Two viewing platforms on the rim of the Big Hole overlook the drop of 175 m with a splendid cross-section of the local geology down to the water level (Fig. 8). The museum

Fig. 8. Kimberley's Big Hole as it appears today. The rim rock is a Jurassic dolerite sill. Below it, the decayed slopes are in the Permian Karoo shales, with the thin Dwyka tillite barely visible at their base. The vertical walls are of Precambrian Ventersdoorp andesites, which faithfully preserve the shape of the mined-out kimberlite pipe.

has a diamond recovery plant and displays on the Big Hole workings in a mining hall, and a prolific display of diamonds in the unmissable diamond hall; these include a very large uncut stone and also the Eureka Stone, the original yellow diamond that the Jacobs children found to play with.

The Bultfontein mine may be visited on underground tours which are operated on most weekdays. These are primarily a tourist facility, but they offer a very easy means for an itinerant geologist to visit a working mine, and the tours go right down into the scraper drifts beneath the caving kimberlite. Tours cost about £7, and it is best to book ahead (phone 0027 531 807270). Another viewing platform overlooks the De Beers pipe, comparable to the Big Hole but without the lake. There are also tours round the few remaining river diggings, at Barkly West, beside the Vaal River some 30 km northwest of town.

Another essential geological site is Nooitgedacht, about 25 km out in the sticks north of town, but easily reached on dirt roads. There the basal Karoo unconformity is exposed on a rock terrace in the Vaal River valley. The Ventersdoorp andesite of the Precambrian

Fig. 9. Palaeozoic glacial striae disappear under the Permian Dwyka tillite at Nooitgedacht – classic evidence of the Permo-Carboniferous glaciation of Gondwanaland.

basement is overlain by the Permian Dwyka tillite – a coarse, fully lithified, glacial till. Palaeozoic ice striations are perfectly preserved on the hard andesite and can be traced to where they disappear under the surviving tillite (Fig. 9). The large areas of striated rock make this a truly impressive site, although it is little visited and is better known locally for the ancient bushmen petroglyphs carved into the ice-polished rock.

Alluvial diamonds

The upper half of each diamond pipe at Kimberley was eroded away long before the miners arrived. This material, together with that from all the other eroded kimberlite pipes in the Kalahari craton, has become the source of the alluvial diamonds. The early rushes of miners worked these shallow placer deposits in the river diggings, totally unaware that the Vaal and Orange Rivers had carried most of the diamonds much further away.

Fig. 10. A migrating barchan dune buries the abandoned track of the Luderitz railway where Namibia's first alluvial diamond was found in 1908.

In 1908, Zacharias Lewala was a track worker on the railway to Luderitz, across what was then German South-west Africa (Fig.10). One day he noticed a stone stuck to the oil on his shovel – and he had found the first alluvial diamond in what is now Namibia. A diamond rush followed and the town of Kolmanskop grew in the desert just a few kilometres inland from the Skeleton Coast. But the mining industry moved further down the coast in 1931, and Kolmanskop is now a ghost town slowly disappearing under the shifting sand dunes.

Namibia's diamonds are in beach sediments. The basic story is that they were carried down to the mouth of the Orange River and then northwards in the longshore drift, although details are much more complex, owing to the timespan of the process, which covers shifting rivers, valleys and coastlines through much of the Tertiary. There are six beach terraces which reach to 90 m above sea level and 3 km inland, besides the modern beach and one palaeobeach now below sea level. The diamonds lie in gravels usually 1–10 m thick, beneath thick covers of barren sand, both marine and aeolian. It is noticeable that the size of the diamonds decreases northwards, away from the Orange River mouth, although beach beds are also mined south of the Orange. The mining is a massive muck-shifting operation to clear the overburden, followed by removal of the diamondiferous gravels, and then careful extraction of the many diamonds caught in fissures and hollows in the gneiss bedrock. Separation of the diamonds is as at Kimberley, and the main plant is now at Oranjemund, a closed company town beside the mouth of the Orange River.

Marine deposits are not restricted to the beaches, and offshore mining started in 1962. Small boats have suction pumps to lift the diamond-bearing gravels from the shallow sea bed. Luderitz is currently the base for more than 30 boats, and there are more based in South Africa's Atlantic ports. In the last ten years the offshore mining has been extended by using robotic sea-bed machines to work in water up to 500 m deep.

Namibia's placer deposits are fabulously rich, owing to a high proportion of gemstone size and quality. Their location on the barren wilderness of the Skeleton Coast is also truly dramatic, although totally inaccessible to the casual visitor. But they all owe their origins to the great kimberlite pipes in the African interior, and the Big Hole at Kimberley remains the enduring symbol of the geology of diamonds.

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Another view of the early diggings at Kimberley's Big Hole (photo from Kimberley Africana Library).