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Diamonds: geology and gems

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HENTHORN, D.I. & HENTHORN, B.J. (1994). Diamonds: geology and gems. *Proceedings of the Shropshire Geological Society*, **10**, 14–18. An overview of the occurrence, exploration and production of diamonds and the manner in which these minerals are developed as gems.

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GEOLOGICAL OCCURRENCE

Diamonds occur in a rare host rock called kimberlite, named after the Secretary of State for the Colonies in the 1870s, although the first description of this rock type predates this and was applied to a rock found (appropriately?) in Ludlowville in New York State. Until the 1950s, the criterion for calling a rock a kimberlite was the presence of diamond: a somewhat strange criterion given that the richest deposits contain less than 1 ppm diamond. Such a description is obviously unacceptable to the petrologist as it excludes all non-diamondiferous pipes of similar lithology and includes another rock type, the lamproite in which diamonds have also been found. Current thinking is to include the kimberlites in a suite of rocks known as ultrapotassic.

It is also necessary to mention alluvial diamonds. Owing to their hardness, diamonds are found in pot-holes, beneath waterfalls, in palaeo-river courses and in marine bench deposits such as those in Namibia. The last occur to the north of the Orange River where it meets a powerful north-flowing marine current. The Orange River drains the interior region of South Africa and it seems probable that such diamonds originate from these areas.

Kimberlite pipes are found only on the ancient cratonic regions of the world with diamondiferous kimberlites restricted to areas older than 2.4 Ga, all those occurring on younger cratons being non-diamondiferous. Although the cratons are old, the intrusions are much younger, and many of the exploited pipes in Africa are 100-200 Ma in age. In North America, four distinct age groupings are recorded within the Phanerozoic. No kimberlites are currently being produced.

Kimberlites are volatile-rich (water and carbon dioxide) potassic ultra-basic rocks rather low in sodium but high in the incompatible elements. Several slides were shown to illustrate kimberlite, typically showing xenocrysts in a grey to dark green matrix. Kimberlites occur in dykes and pipes often grouped together in clusters. Inclusions of other mantle material are fairly common.

Petrographically, kimberlites are complex and often categorised into two groups depending on whether mica is present or not. Both types can have diamonds. Nd-Sr-Pb isotope ratios suggest an origin for group 1 (the non-micaceous) of the asthenosphere mantle, whereas group 2 comes from an enriched mantle source in the lithosphere. Emplacement must occur fairly rapidly since both diamond and coesite are unstable at the normal conditions met in the upper crust. Angularity of xenoliths (illustrated by Dwyka Tillite fragments in a sample) also supports this, as does the retention of hydrocarbons in certain hydrocarbon xenoliths.

Pipes (see Figure 1) are of limited diameter (Premier mine: 31 ha, Kimberley: 4 ha, and Dutoitspan: 12 ha). Emplacement seems to occur along deep-seated lines or fissures following definite lines of stress. The magma rises to a depth of 2-3 km and at this point the carbon dioxide undergoes rapid expansion creating fluidisation and a rapid burst through of material to the surface. Thus, although emplacement occurs at relatively low temperatures, speeds of 400 m/s have been suggested. Referring to Figure 1, dykes from depth establish a root-zone at 2-3 km and then the material bursts forth to produce a diatreme with pyroclastics at the surface. It is believed that the Mwadui mine of Tanzania is currently working fairly dose to the surface, whilst Southern African mines are working material from deeper down a stylized section. Supporting drill evidence at Kimberley does suggest that this pipe opens out at depth.

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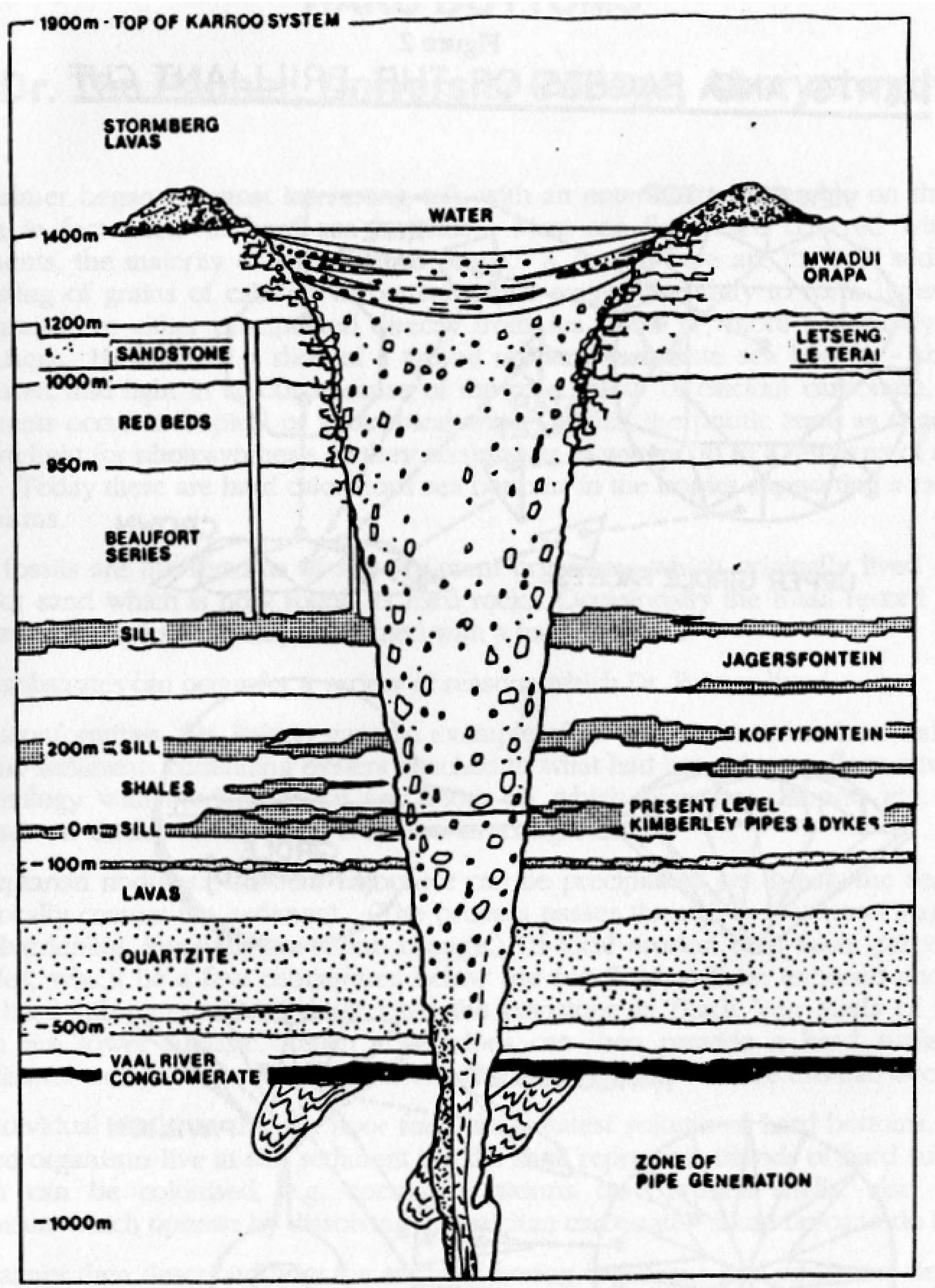

Figure 1: Diagrammatic section of a kimberlite pipe in the Kimberley area before erosion, based on a model by J.B. Hawthorne, Chief Geologist of De Beers Consolidated Mines, Kimberley.

Diamonds are probably xenocrysts and their formation is not contemporaneous with their emplacing kimberlite. Rb/Sr and Nd/Sm ages on diamonds from Finsch and Kimberley mines yield ages of 2.2-2.3 Ga compared with Jurassic/Cretaceous ages for the host rock. Pressure/temperature graphs for the stability of quartz/coesite, graphite/diamond and coesite/stishovite, coupled with thermal conductivity of 40 mW/m (typical of cratonic regions), suggest a minimum depth of formation of 140 km.

Diamonds may be categorised into two groups and, although each group may be present in a single crystal, one type will normally dominate. Type 1 diamonds usually have good crystal form, but various inclusions. Type 2 diamonds tend to be purer, but of poor crystal shape. Nearly all large diamonds fall into type 2: the Cullinan is very definitely type 2. An illustrative slide was used to show the wide variety of colours in which diamonds can occur: yellows, blues, browns, even black. Colour seems to be determined by trace elements: brown by magnesium, green by iron etc., although the black, which contains graphite, may represent a diamond which was dose to inversion to graphite. It is yet uncertain whether these traces are present as lattice irregularities or as micro-inclusions of contemporary age.

EXPLORATION

Moving on to consider exploration, most of the usual techniques have been applied in the search for diamonds, but it tends to be a bit hit-and-miss when geophysical techniques are used. Airborne techniques have been successful, but many pipes are only of comparable size to the line spacing, and the physical properties of the country rock are often very similar to that of the intruded kimberlite. Seismics have had little success, whilst gravity has proved useful in identifying pot holes etc. but is a fairly expensive technique and of little use in wild-catting. Magnetics can be useful, but not all kimberlites produce magnetic anomalies and not all of those which do are diamondiferous.

The difficulty of identifying diamondiferous ground was exemplified by a leading mining house in South Africa who abandoned a claim on a circular anomaly after their geologists declared it to be a meta-sediment. The claim was bought by De Beers who have since identified it to be not only a kimberlite, but richly diamondiferous! Within the last month (November 1992), diamonds have been claimed in a bore hole in the North-West Territories of Canada. After much frenzied activity on the financial markets and staking of claims by those not wishing to be left out, the original drillers were forced to admit that on re-examination of the material, the diamonds originated from the drilling crown!

PRODUCTION

To extract diamonds from alluvium, beach deposits or the weathered kimberlite (or yellow ground) requires little more than a shovel and separator (often a rotating cage known as a tromell) and a keen eye. Slides were shown of some "one-man-and-a-dog" type operations which are still in use in the Transvaal.

On a larger scale, and also as a final stage in extraction from the unweathered kimberlite (blue ground), a unique property of diamond is used. This is its unwettability. If water is sprayed over most rocks, they become wet, and will not adhere to grease. Not so diamond. The diamond adheres to grease-covered rollers while the gangue material falls away. At the end of the day, the grease is melted, and the diamonds fall to the bottom.

Mining blue ground (which is anything but blue, rather grey-dark-green) is the realm of the more serious undertaking. Most modem mines are open-cast, but at Kimberley and at Cullinan, deep mining occurs. Deep mining was introduced when the original holes had reached such a depth that stability was a problem. A shaft was sunk through the country rock and then tunnels driven into the pipe. One problem with drilling kimberlite is that it swells when wet, binding the drill. However, dry drilling is impossibly dusty and has all the inherent health problems.

A new technique known as block caving was developed to extract kimberlite. A main rock shaft is drilled down some distance from the kimberlite pipe. At a suitable depth a full circular haulage is cut right around the pipe. From the haulage, they drive "scraper drives" upwards into the kimberlite. The scraper drives are lined with concrete and at intervals "doorways" leading into chambers some 2 m high and 4 m in each direction are made. The kimberlite collapses into these caverns and spills into the scraper drive from where it is removed with a scraper (which is not much more than a steel bar) into the haulage. This way, virtually no drilling or explosives are necessary after the initial stage of development. Once overburden appears, the haulage is abandoned and a new haulage constructed 400 m deeper.

The first processing of the kimberlite is to be screened by human eye for large diamonds. They are rare, but it is still economically viable. Subsequently the blue ground is crushed and the material screened by ultra-violet fluorescence. Most diamonds, when subjected to ultra-violet, fluoresce in the visible spectrum. Sensing is electronic, and they are removed using air guns. Further crushing occurs and then small diamonds are entrapped using grease tables.

The first part of the presentation concluded with slides comparing early Kimberley and modern-day Angola where a free for all has developed in alluvial diamonds. Reference was made to the cartel system of trading diamonds through the Central Buying Organisation and the Central Selling Organisation pointing out how the price of diamonds is fixed, but adding that recently some very good stones (particularly from Angola) had found their way to the Antwerp market and that this was seriously pressurising the cartel. The final slide showed one day's production from Premier mine: mostly boart, but some gemstones.

FROM MINERAL TO GEM

The availability of diamonds stems from the South African discoveries of the 19th century. Prior to that diamonds were known from India, but only in quantities that could be described as regal. Tradition suggests that the first diamond in Africa was found in the Orange River area by a Griqua boy who had been sent out to clear a drainage hole in a dam, when out popped a "mooi klip". This stone was later seen by a visiting general dealer who took it to Cape Town and subsequently to England. It took three years before it had been verified as a diamond. The rough stone weighed 21 carats and after cutting yielded the 10.75 carat Eureka diamond.

In 1871, a group of men known as the "red caps" sent one of their number out into the veld and told him not to return until he had found a diamond. Waking under a tree the following morning, lo and behold, there was a diamond. Where he had slept was ultimately to become the Kimberley "Big Hole", although at that time it was a small hill. 2.75 tons of diamonds were extracted before the mine was abandoned in 1914.

Only 20% of diamonds are gem quality, the rest being known as boart. Diamonds are categorised according to "the 4 Cs": Cut, Carat, Clarity and Colour.

Cut; All diamonds used in jewellery are cut. The major cutting centres of the world are Antwerp, Tel Aviv, Amsterdam, and London. Most diamonds are cut to a cone shape known as a "brilliant". This cut was developed to give maximum scintillation from the stone. Diamonds cut prior to 1919 (when this cut was first used) have far less scintillation and hence less value. One of the most common crystalline forms of diamond is the octahedron. By simply slicing the top off, we get close to the "standard" shape. For a 1-carat stone, it takes a day to make the initial cut. Only diamond cuts diamond, and then only slowly. The ideal diamond is 2/3 pavilion, 1/3 crown (Figure 2). If the proportions are not right, light will not be totally internally reflected and hence the emergent light will be less intense. Thus cut is the most important of the four Cs.

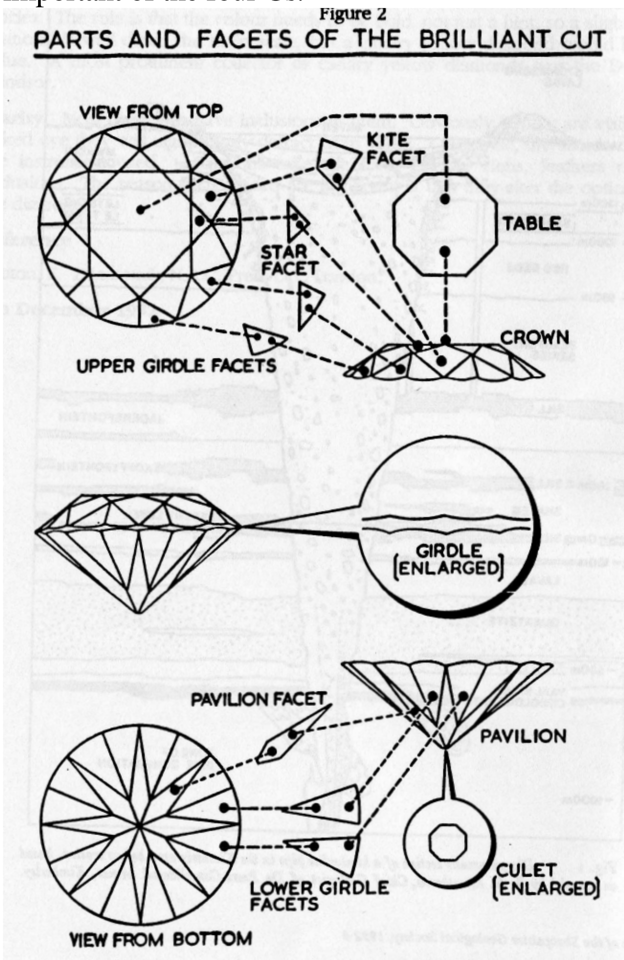

Figure 2: Parts and facets of the Brilliant Cut.

Carats; The name derives from the seed of the carob tree. Around 4000 BC such seeds were used to weigh diamonds in India. The modern carat is 1/5 gram and, as a check, the authors weighed a number of the seeds and found most to be within 5% of the modern value. The subdivision of the carat is the "point" of which there are 100 to the carat. The average English engagement ring is 8 points. "Are you a girl in a million?" is a phrase used by De Beers in their advertisements. Why? Well, simply only 1 diamond in every 1 million weighs 1 carat or more.

Colours; Although "white" and "icy" may be the average person's description of a diamond, there are 25 colours recognised in the trade ranging from D to X. J or K would be described as slightly tinted white. A-C are only found as investment stones. Colour acceptability varies from country to country. In Germany, whiteness is all important, whereas in the UK one would be prepared to sacrifice colour to some degree if the other Cs were good. Additionally, diamonds occur in colours and these are known as fancies. The rule is that the colour needs to be bold, not just a hint, so a slightly yellow diamond is well down the main scale, but a canary yellow diamond would have high value. A most prominent collector of canary yellow diamonds was the Duchess of Windsor.

Clarity; Most diamonds have inclusions in them. Obviously, if they are visible to the naked eye they will significantly detract from the value. Otherwise, the standard loupe is the instrument used. Inclusions take the form of tiny clefts, feathers or carbon inclusions. The reason such defects are important is that they alter the optical path of the diamond.

Further detail can be read in the book written by Eric Bruton (1992).

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