Diamond Geology

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A) CLASSIFICATION AND GENETIC MODELS

Diamond deposits can be classified as primary (kimberlites and lamproites) and secondary (alluvial and marine). In 1995, their relative production contributions in South Africa were, primary (kimberlite) 8.63 million carats (89% of total), alluvial 960,000 carats (10%), and marine 90,000 carats (1%). The percentage of gems in kimberlites is highly variable. Published figures suggest approximately 40% for the Kimberley mines and 55% for Premier mine. The proportion of gems in the West Coast marine deposits is over 98%. The MIBA mine in the Congo and the Argyle mine in Australia have an average gem content of only 5%. The dispersal of diamonds from their primary sources into streams and rivers and ultimately to the sea is generally accompanied by an increase in average value per carat, as flawed stones are progressively destroyed with greater and greater transport.

Diamonds are known to occur in a variety of rocks, including high-pressure metamorphic rocks such as garnet-biotite gneisses of northern Kazakhstan, alpine-type peridotites, and meteorites. However, the only known economically significant primary sources of diamond are kimberlite and lamproite. The Argyle lamproite pipe, in north-western Australia, is the largest known diamond producer. No significantly diamondiferous lamproites are known in South Africa where the primary sources mined are kimberlite pipes and dykes. Kimberlite is defined as a volatile-rich, potassic, ultrabasic igneous rock that occurs as small volcanic pipes, dykes and sills. It has an inequigranular texture resulting from the presence of macrocrysts (phenocrysts and xenocrysts) set in a fine-grained matrix. The mineralogy comprises olivine with several of the following: phlogopite, calcite, serpentine, diopside, monticellite, apatite, perovskite, and ilmenite. Kimberlite often contains fragments of upper-mantle derived ultramafic rocks, including xenocrysts such as pyrope garnet, picro-ilmenite, chromian spinel and chrome-diopside. Kimberlite may contain diamond, but as a very rare constituent.

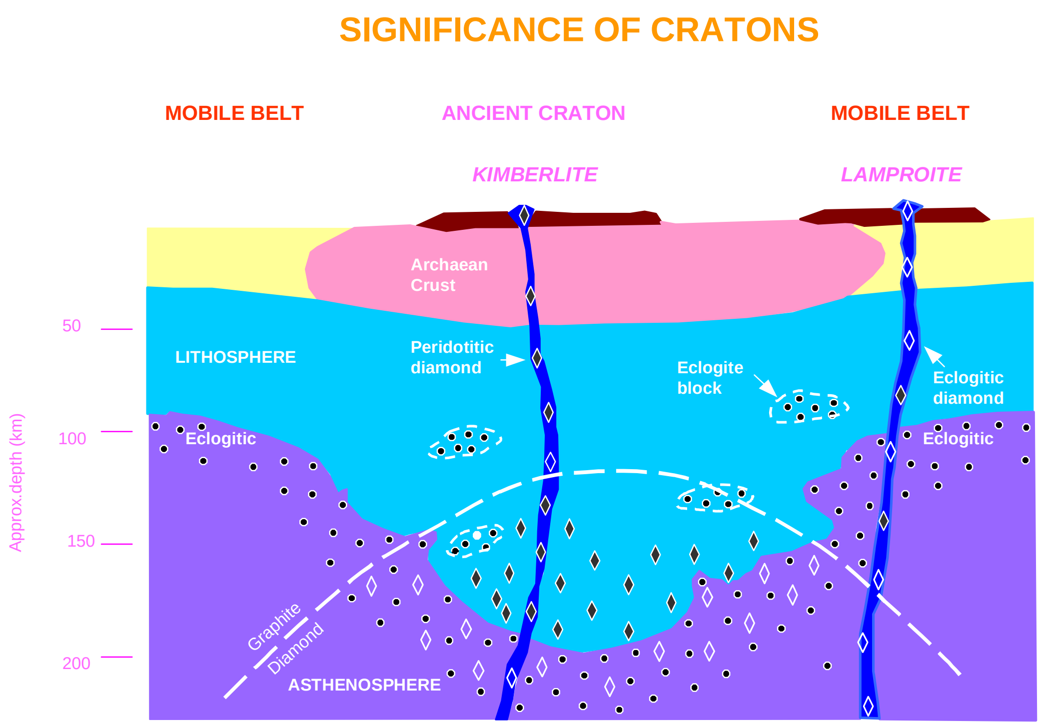
Two distinct types of kimberlite are recognised: Group I, or olivine-rich, monticellite-serpentine-calcite kimberlites and Group II, or micaceous kimberlites. Historically, these were respectively referred to as “basaltic” and “micaceous lamprophyric” kimberlites. These distinctive groups are derived from sources in the earth’s mantle that are either slightly depleted (Group I), or enriched (Group II) with respect to light rare earth elements. This enrichment and depletion is evidence of past metasomatic processes occurring in the mantle.

Only a small proportion of known kimberlites carry diamonds. Of the approximately one thousand individual kimberlite intrusions known in South Africa, only about fifty carry significant quantities of diamonds. Of these, many are considered subeconomic either because the quantity or quality of the diamonds, or the quantity of ore is insufficient. It is difficult to predict whether or not a kimberlite will carry diamonds without actually testing it. The grade of a diamondiferous orebody is usually expressed as carats per hundred tons (cpht). A grade of 136 cpht (the grade of Venetia in 1995) equates to about 0.272 parts per million! The presence and quality of diamonds in a kimberlite can only be determined with confidence by the collection and processing of a large and representative sample.

Regional Setting of Primary Diamond Deposits

"Clifford's Rule", states that diamondiferous kimberlites are almost exclusively found in regions underlain by Archaean craton, that is continental crust older than 2.5 billion years in age. In Africa, Russia and Canada, all of the significantly diamondiferous kimberlites are "on-craton". The only significant exception to Clifford's Rule is the Argyle lamproite in Australia. It lies "off-craton" in a Proterozoic mobile belt.

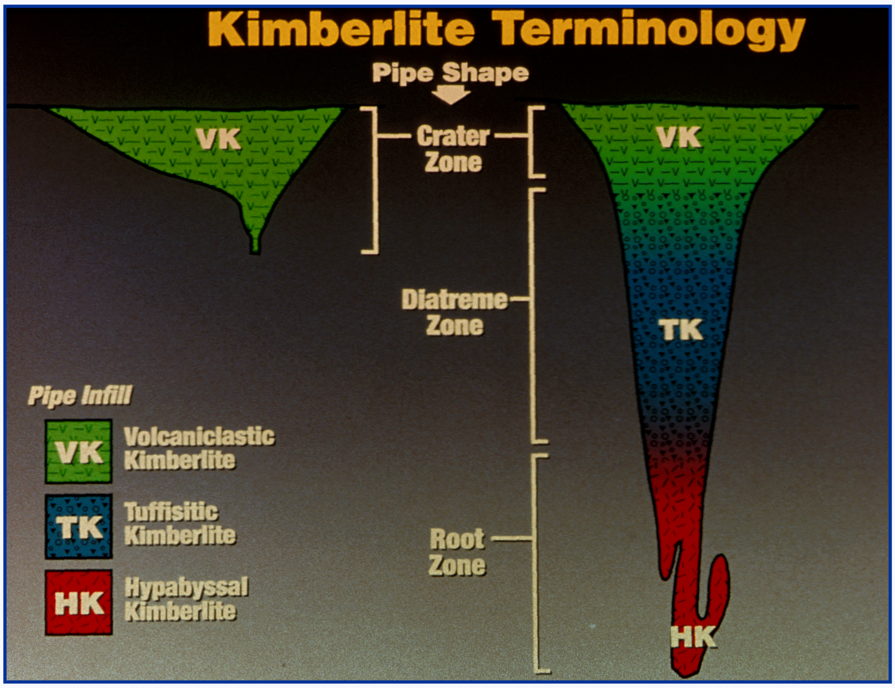
The reason for the originally empirical association between Archaean basement and diamondiferous kimberlites has been explained theoretically by consideration of the structure of the cratons (elucidated by geophysics and the study of mantle xenoliths brought to surface by kimberlites), and the temperature/pressure relationship between graphite and diamond. Natural diamonds form and are preserved in a high-pressure environment present in nature at depths of over 120 kilometres. In most parts of the Earth, the temperatures at this depth are too high for diamonds to form. However Archaean cratons have relatively cool lithospheric roots in which there exists a downward deflection of isotherms and a corresponding upward deflection of the diamond stability field.



This region of high pressure and relatively low temperature (less than about 1200°C) provides a "window" in which diamonds can form and be preserved. Kimberlitic magmas are generated at or below these depths (as evidenced by their xenoliths), and may "sample" the lithospheric roots, thus collecting diamonds en route to surface. Kimberlites formed away from the craton do not sample the diamond window, and thus are unlikely to be diamondiferous.

From work done on kimberlites in many parts of the world, three broadly distinct vertical zones are recognised, the crater, diatreme, and root zones. The crater represents the uppermost portion of the pipe and is characterised by well-bedded, poorly consolidated sediments with chaotic debris-flow deposits and pyroclastics. The diatreme is volumetrically the most significant, and comprises an easily weathered breccia consisting of angular country rock xenoliths and fragments of mantle-derived material set in a fine-grained matrix. This is known as a tuffisitic kimberlite breccia or TKB. The root zone is composed of magmatic or hypabyssal material usually porphyritic in appearance, containing macrocrysts of olivine and phlogopite set in a fine-grained matrix, often with xenocrystic garnet, ilmenite, spinel and chrome-diopside. Mining difficulties may be experienced in the hypabyssal facies due to the irregular shapes of the intrusion. Mining in the Kimberley mines is now into the root zones of the pipes.

Model of a Kimberlite Pipe



Field & Scott Smith 1998

The presence and degree of preservation of these zones depends upon the level of erosion, the volatile content of the erupting magma and the stability and nature of the country rock. The large, economically important kimberlites at Orapa and Jwaneng in Botswana have suffered very little erosion, and their crater facies are still preserved. The Kimberley, Jagersfontein, and Koffiefontein pipes are smaller and are eroded down to the diatreme zone.

Secondary deposits

The erosion of diamondiferous kimberlites liberates diamonds onto the land surface, for redistribution by streams and rivers. The processes that lead to the deposition and concentration of diamond in river sediments are obviously of direct importance in the formation of economic alluvial diamond deposits (or diamond placers). They also carry a secondary significance in concentrating associated indicator minerals such as garnet, ilmenite, spinel and chrome-diopside that guide prospectors to the primary sources. Diamonds preferentially concentrate in suitable secondary environments due to their exceptional resistance to chemical and physical breakdown, and high specific gravity of 3.52 (compared to quartz at 2.67). The indicator minerals have comparable properties, but are far less resistant.

Major alluvial diamond deposits develop on or adjacent to cratonic source areas where there is a favourable interplay between climatic, basin dynamic, and local geomorphic factors. Regions where humid tropical palaeo-climatic conditions have alternated with semi-arid conditions are most favoured. The deep weathering of rocks during humid periods leads to efficient liberation of resistant minerals and the subsequent stripping of the deep regolith during semi-arid phases leads to the transportation of the released diamonds. Changes in the base level of a river basin produce alternating periods of local sediment erosion (degradation) and deposition (aggradation) that are conducive to the local concentration of diamond. Terraces also develop as the river cuts downwards to equilibrate with a lowered base-level. A *terrace* is a preserved section of river sediment abandoned by a river as it incises downwards in response to a lowering of its base level (for example by a lowering of sea level). Terraces may occur at different heights above present day river level, the higher terraces being the oldest.

Local geomorphic factors influencing alluvial diamond concentration include bedrock lithology and topography. Bedrock that erodes to produce good trap sites such as gullies and potholes and also contributes coarse clasts to the river sediment tends to produce the richest alluvial deposits. In South Africa, there is a strong correlation between alluvial diamond deposits and Ventersdorp lava bedrock in the Vaal-Harts River basin. The diamonds tend to concentrate in the lower parts of a deposit, trapped in bedrock irregularities such as potholes. Whilst the pothole is active (i.e. sediment is passing through and light material is escaping whilst heavy minerals remain), attrition between minerals occurs until a critical size is attained, at which time a mineral is washed out. Since diamonds are very hard, they suffer very little attrition, and are further concentrated relative to other heavy minerals. The longer a pothole is active, the higher the relative diamond concentration may become. Changes in slope and sites where rivers exit from the confines of gorges are also favoured localities for the development of such placers.

The return of humid tropical conditions after the formation of a diamondiferous terrace may lead to the enrichment of the terrace. As the material weathers, the labile component will be washed out, leaving a deposit enriched in resistant minerals such as quartz, agate and diamond. The highest (and oldest) “Rooikoppie” gravel terraces of the Vaal River basin are a good example.

Alluvial deposits may become lithified to form solid rock and these are commonly known as palaeo-placers. The Witwatersrand gold deposits are an example, and in fact they have produced minor quantities of diamond along with other by-products. In one year, the Modderfontein “B” Mine reported a total of 194 carats.

Diamonds introduced to the continental margin may become concentrated if deposited on a stable surface such as the continental shelf off South Africa and Namibia. Periodical reworking of the diamondiferous material by sea-level regression and transgression may enrich the deposit. The enormous deposits on the West Coast of southern Africa are at present, unique in the world.

B) EXPLORATION

1 Introduction

Exploration is conducted in the phases of target selection, reconnaissance and follow-up, drilling and evaluation. Although a phased approach is adopted, there is often justification in short-circuiting the "exploration pipeline" to arrive at risk decisions more quickly. The two principal methods used in prospecting for kimberlites are sampling for heavy (indicator) minerals such as pyrope garnet, picro-ilmenite, chromian spinel (chromite) and chrome-diopsides (clinopyroxenes), and geophysical techniques. From each of these methods, targets or anomalies are generated and refined by further detailed follow-up work, culminating in the drilling of the target. A recent technical development is the AMSS, or Airborne Multi-Spectral Scanner, which can detect weathered kimberlites (without cover) by the very specific electromagnetic wavelength absorption caused by the magnesium-rich clay minerals produced by weathering of kimberlites.

Once a kimberlite is identified, subsequent work is aimed at determining the economic parameters of size, grade, value, and potential mining cost. The important strategic advantage is gained by targeting areas most likely to host diamondiferous kimberlites as opposed to just kimberlites, to applying appropriate technology to the specific project, and to making walk-away/proceed decisions as early as possible in the exploration process, without walking away from potential mines. Hence exploration is a process of risk management.

2 Target Selection

Using information that is known about the genesis and emplacement of diamond deposits, an exploration model is established. For kimberlites, prospective areas can be identified and prioritised on both a regional and local scale. The identification of these target areas involves the integration of data sets relating to:

- Global, regional and local tectonics (e.g. where are the world's preserved Archaean cartons?)
- Lithospheric structure and composition (e.g. Is the lithosphere in a given area thick enough to extend into the diamond stability field?)
- Diamond formation and preservation (e.g. Have any processes occurred, such as rifting, that would destroy diamonds?)
- Known host rock petrogenesis and emplacement (e.g. in what host rocks do we expect to find diamonds in this area?)
- Country rock and source rock geochronology (e.g. Do we expect kimberlites to intrude through, or be covered by, sedimentary cover sequences in this area?)
- Local tectonic controls (e.g. are there any local structures that might control the emplacement of kimberlites?)

Information is collected from various sources and includes published maps and technical reports, geophysical databases and interpretations, remote sensing data, and in-house databases. Target selection is an iterative process, and areas are constantly reprioritised with the availability of new data and techniques. This information can be added to a wider process with prospectibility and risk inputs, to produce a Prospectivity vs Risk matrix.

Once target areas are defined, a decision must be made on what prospecting methods will be most effective for the area. For example in geo-magnetically “busy” areas (e.g. banded ironstone formations) airborne magnetic surveys would be unlikely to detect kimberlite intrusions. In parts of Australia, the regolith is so mature that indicator minerals hardly survive, and alternative techniques may be required. A combination of techniques is often most effective.

3 Heavy Mineral Sampling

Indicator mineral techniques used in exploration for primary deposits are based upon the preservation of certain kimberlitic mineral species in the secondary environment, and studies of the upper mantle from where these minerals originate.

“Heavy minerals” are a select group characterised by their high specific gravity (generally greater than quartz at 2.67). Most are resistant in the secondary environment and many are oxides. The important heavy minerals in kimberlite exploration are mantle-derived xenocrysts of pyrope garnet, picro-ilmenite, chromian spinel (chromite), chrome diopside (a variety of clinopyroxene) and of course diamond. In cold climates, where chemical weathering of minerals occurs at a much slower rate (e.g. in Canada), olivine may also be important. These minerals are released into the secondary environment by weathering and erosion of a kimberlite intrusion, whilst the bulk of the kimberlite rock (comprising largely olivine, and serpentine) weathers to clay minerals which are easily transported away by wind and water. The presence of these indicator minerals in soil and stream samples points to the local presence of their source kimberlites. An important point to note is that the presence of diamonds alone in such samples may be a red herring, since diamonds are so extremely resistant in the secondary environment, that they may survive several sedimentary cycles and occur in concentration far from their primary source.

If a Heavy Mineral sampling project is to be undertaken, consideration of the geomorphology is most important to determine such parameters as sample size, sample medium (stream sediment or soil), sampling interval, size-fraction to be analysed, and analytical techniques. The sampling process is staged from reconnaissance work to more detailed follow-up to first identify regional anomalies, and then to delineate specific targets for drilling. The sample parameters may change as the targets become more focussed. For example it is difficult to define a drill target using a stream sampling technique, and using coarser size-fractions in the detailed follow-up stage may help define a drilling target.

Depending on the topography and geology, sampling intervals vary. In flat terrain where there is limited transport of indicator minerals from the kimberlite source, or in metamorphic terrains with heavy mineral backgrounds (e.g. in parts of the Zimbabwe low-veld) large samples may be taken on a close interval grid (say, 1km). In hilly, well-drained areas, stream transport and concentration of indicator minerals occurs, and much wider spaced samples may be collected. During a recent reconnaissance sampling program in West Africa stream samples were collected at an average density of 1 in 25km^2. In glaciated terrain, glaciers and glacial streams disperse the indicator minerals and a sample every 5 to 10km^2 is the norm.

In the field, the co-ordinates of each sample site are recorded (usually with a GPS), with a description of the site and other parameters. The processing of the sample to produce a heavy mineral concentrate varies according to the environmental factors and requirements of the project. It is important that an appropriate process is applied to maximise effectiveness and minimise cost.

The sample may be screened in the field, and is transported to a processing facility where a heavy mineral concentrate is produced. This may be a relatively hi-tech process involving mechanical screening and a mini-DMS, or lo-tech, involving manual labour. Most concentrates are sent to one of the HM laboratories for analysis, although for follow-up work, field examination of the concentrates can accelerate the result turnaround. At the laboratory, the mineral concentrates are further concentrated if necessary, and are examined under binocular microscope for mineral grains that may be derived from a kimberlite. These are extracted from the sample, and if necessary their colour, shape and surface features are described to provide information on transport history.

Geochemical analysis of indicator minerals by electron microprobe is carried out routinely at the GeoScience Centre (GSC). The results of this analysis provide two important types of information. First, are the minerals mantle-derived or not. Second, are they derived from inside or outside the diamond stability field? Recent developments in trace-element analysis provide further information regarding the geothermal gradient within the mantle (important for interpreting likely preservation or resorbtion of diamonds), and confirming derivation from inside or outside the diamond stability field. This data provides information useful in determining if the source kimberlites are likely to be diamondiferous (and therefore worth finding), and also for prioritising areas for follow-up.

Collecting a Heavy Mineral Stream sample in Russia

Areas identified as anomalous and of interest are followed up at closer sample intervals accompanied by geological and terrain mapping, the objective being to generate drill targets.

4 Geophysics

Geophysical techniques are applied in diamond exploration on a regional scale to delineate structure and to help define cratonic areas and on a local scale to detect anomalies associated with kimberlite intrusions. They may also be used during drilling in the form of a down-the-hole tool designed to collect information useful in logging a borehole. Although geophysical techniques have discovered a large number of kimberlites, no diamond mine has yet been discovered using geophysical techniques as the primary tool.

Conducting an Electromagnetic Survey in Zimbabwe

In mineral prospecting, a technique is required that will distinguish the physical properties of the ore rock from the country rocks. This may be the density, the radiometric properties, the electromagnetic properties or other physical characteristics. By far the most common technique in kimberlite prospecting is to fly an airborne geomagnetic survey, which maps the perturbations of the earth's magnetic field induced by the local geology. Kimberlites can usually be recognised from such surveys if their magnetic susceptibility is different from that of the country rocks. However, this is not always the case, and Venetia, Jwaneng, Marsfontein and Mwadui are all examples of kimberlites that do not provide an anomalous response.

Once a survey has been flown, the data is processed and interpreted. A large number of targets (or anomalies) may be selected for follow-up, and ranked according to how likely (in the geophysicist's opinion) the anomaly is to be associated with a kimberlite, how large the targets are, or by other parameters. Follow-up of targets may be ground- or helicopter-based, and is designed to produce high-resolution data that can be better interpreted and on which boreholes may be sited. The target may also be sampled for indicator minerals (unless the target is covered) to help prioritise further work.

Other frequently used geophysical methods include Electromagnetics (EM), very low frequency (VLF) and gravity.

The electromagnetic technique (e.g. horizontal loop EM) has been applied in regions of high weathering resulting in enhanced differential conductivity between kimberlite and country rock. However, in low latitudes, weathering profiles are often highly developed, and conductive overburden reduces the effectiveness of the technique. In high latitudes such as in Canada, relatively recent glacial events have stripped this regolith, and kimberlites often produce very distinct anomalies.

VLF surveys have been quite effective where structural controls (e.g. structural lineaments) have played a role in kimberlite emplacement.

Gravity surveys depend on density contrasts between kimberlite and country rocks. The gravity technique is ground-based (although efforts are being made to develop airborne systems), and is slow and laborious to undertake. However, it may be used to delineate an intrusion.

Conducting a ground Magnetics survey in Tanzania

5 Drilling & Analysis

The objective of this phase to collect samples to identify the rock types (kimberlite, facies, etc.), mode of intrusion (pipe, dyke, sill), preliminary size and to determine the presence of microdiamonds and mantle-derived xenocrysts that originated from the diamond stability field. Rock samples are sent to the GeoScience Centre for the following analyses:

- **Petrography**

  The detailed description of the mineralogy and texture of rocks. This is done in order to identify and classify the rock on the basis of mineralogy, and to rate the potential of the rock to contain diamond.

- **Heavy mineral abundance and mineral chemistry analyses**

  Indicator mineral grains are extracted form the rock by partial acid digestion at the Kimberley Acid Laboratory (KAL) and are then mounted and analysed by electron microprobe. The relative abundance of minerals helps “fingerprint” the source kimberlite, and the absolute abundance is an indication of the degree of mantle sampling. The major element composition of the minerals gives an indication of whether or not sampling took place within the diamond stability field.

- **Trace Element chemistry**

  Indicator mineral grains may be analysed by Laser ablation ICP-MS in order to determine trace element geochemistry. This data provides information on the geotherm at the time that the kimberlite sampled the mantle (important because elevated geotherms promote resorption of diamonds), and also provides semi-quantitative information on the degree of sampling within the diamond stability field.

- **Argon - Argon dating**

  Dating of kimberlitic intrusions using the Argon-Argon technique can be performed at the GSC or if other techniques are required, at public institutions. Age information is important in exploration to establish stratigraphic relationships between the kimberlite intrusions and the regional geology. Dating of basement rocks is used to identify cratonic terranes, which helps constrain target areas.

If the rock sample collected is identified as potentially diamondiferous, a sample is submitted to the KAL for microdiamond analysis. Microdiamonds are defined as diamonds under 0.5 mm in diameter. Microdiamond data is a relatively cheap technique used to obtain a first order estimate of grade.

Target drilling in Russia

At this point in the exploration process, the economic information that is available is the likely grade of the kimberlite, it's approximate size at surface, and the environment in which it occurs (nature of cover, distance from existing infrastructure, political stability of the country, etc.). Estimating parameters such as capital costs, operating costs, etc can contribute to a very rough economic model of the deposit. However, the parameter to which most diamond projects are most sensitive is value. No diamond value data is available at this point in a project. A risk decision is made to abandon the property, to hold it, or to proceed to the evaluation stage. This decision is based mainly on the microdiamond (grade) and size (tonnage) data.

De Beers drilled approximately 2,000 new kimberlite discoveries during the last 20 years, and only about 2.5% of these were found to have a grade of greater than 10 cpht. Collection of data that adds to the cost of the initial drilling programme and may only be useful during the evaluation process cannot always be justified, because in the vast majority of cases, no further work is undertaken on a kimberlite.

C) EVALUATION

1 Introduction

The evaluation of a diamond deposit is the process followed to establish economic viability, and in some cases, to identify the “footprint” of the deposit. The “footprint” is a profile of the type of diamonds present, which may be important for market planning. Economic sensitivity analyses indicate that all diamond deposits are most sensitive to diamond value and grade, and these are the dominant factors that influence the decision to proceed with a project. Metallurgical, geotechnical, and other information is vital to mine development, but it is the variables of grade and value on which the decision to proceed or not is based. It follows that the evaluation process is driven by the objective of establishing these parameters first. A risk decision may be made to collect ancillary information such as ore characteristic data at an early stage of a project, if the cost/risk profile of the decision is favourable. For example, if the cost of mobilising a drill to collect core is unusually high (as in the Northwest Territories of Canada), then core may be collected for this purpose before a decision has been made to proceed with the project.

As soon as it the opportunity to collect geotechnical, metallurgical, environmental etc. data becomes available, it is important that this expertise is incorporated into the team undertaking the project.

The sampling methodology applied to various types of diamond bearing deposits is generally similar. The objective of the sampling is to obtain accurate estimates of the in-situ volume, diamond content and potential revenue of the deposit with increasing levels of confidence.

The Evaluation Phases

A phased approach to evaluation is adopted because of the relatively high cost involved in collecting and processing macrodiamond samples. The objective of the preliminary evaluation phase is to establish the global macrodiamond grade and an initial estimate of value per carat to arrive at an Inferred Resource. If the results of this work are favourable, the project may move on to the evaluation phase, where local grades and macrodiamond values are established to arrive at a Measured Resource. If conceptual economic modelling of the measured resource indicates that the deposit may be viable, then the project moves to the feasibility phase. In many cases, a risk decision may be made to skip phases of the process. An example was the Oaks Mine, which proceeded to feasibility and mining directly from the preliminary evaluation stage.

A risk decision is made each time a project moves or does not move from one phase to the next. The way risk decisions are managed is to enter the available geological data into economic models with variables such as operating costs, capital costs, recovery factors, dilution, stripping ratios, etc. In this way, projects that are most likely and least likely to be viable can be prioritised, held or abandoned. The effect of changes in parameters such as diamond values, new technology, royalties, etc, can then be recognised in terms of their effect on the potential return on investment for a project.

2 Preliminary Evaluation Phase

The objective of the preliminary evaluation phase is to determine a ballpark estimate of grade and size and thus possible in-situ value of the deposit. This is normally established by collecting mini-bulk samples totalling between 20 and 200 tonnes by the most cost-effective method available. Drilling is the most common technique, since it is relatively cheap, can penetrate overburden and provides a sample representative of a larger part of the kimberlite. However, there is always some diamond damage associated with drilling.

3 Evaluation Phase

The major objective of the evaluation phase is to determine the grade and value of the deposit more accurately. In order to achieve this thoroughly, an estimated 3000 carats of diamonds need to be produced per major kimberlite facies. These are recovered from bulk samples which may total several thousend tonnes. Again, a risk decision may be made to collect less than this (or not do it at all) if the results of previous work appear sufficiently attractive.

The sample information collected during this phase is essential for mine (including treatment plant) design.

4 Feasibility Phase

Feasibilty is the process of incorporating the geological model into a detailed mining scenario model incorporating geotechnical, engineering, fiscal, environmental and metallurgical parameters, to determine the probable return on investment, and how best to mine it. It is the process that turns a resource into a reserve.

5 Sample Treatment

The processing of geological samples utilises metallurgical processes to extract macrodiamonds. However, the objectives of the metallurgical processes utilised on a mine, and those utilised in processing geological samples are different. On a mine, the objective is to generate optimum revenue. With a sample, the objective is to generate information. The geological samples produced during the bulk sampling of a deposit are treateded by the Geological Sample Processing Services (GSPS) at CHQ.

D) WORLD PRODUCTION

South Africa has been a major contributor to world diamond production since 1869 when the first diamond rush occurred on the Vaal River alluvial deposits. Between 1872 and 1908, at the start of Namibian production, the country was producing more than 97% of the world's diamonds. This domination continued, with South Africa annually producing more than half the world's supply, until the early 1930s, when several factors combined to dramatically reduce the country's share of production.

The Kimberley Mine closed in 1914, whilst production from other African countries grew rapidly with discoveries in the Congo, Guyana, Angola, Ghana and Tanzania from 1914 to 1925. The collapse of the New York stock exchange in October 1929 and the subsequent Great Depression had a severe effect on the mining industry in general, but particularly on the luxury diamond market. Major high-quality diamond finds in Sierra Leone in 1932 made it difficult for South African producers to compete as the world economy recovered. The 1939-1945 war also had a negative impact on the country's production, as the world market contracted and labour became scarce. After the war, South Africa's share of world diamond production grew steadily from less than 10% to more than 25% in 1981. This occurred despite major discoveries from 1957 to 1970 in Guinea, Ivory Coast, Liberia, Russia and Botswana. The opening of the Argyle mine in Australia in 1983 had a profound effect on world production, moving Australia from non-producer status to the number one spot with an annual production of over 35 million low quality carats, accounting for only 6% by value of world production.

E) SOUTH AFRICAN DIAMOND OCCURANCES

The total quantity of diamond mined in the world up to 1995 is estimated at approximately 2.67 billion carats or about 534 tonnes. Of this total, South Africa has contributed 493 million carats, or 18% of all natural diamonds. Today, South Africa ranks fifth in world diamond production by volume, behind Australia, Botswana, Russia and Congo, annually producing approximately 10% of the world's supply. By value, only Botswana and Russia exceed South Africa's contribution. During 1995, diamond production in South Africa was 9.69 million carats, of which more than 93% was from the De Beers mines at Venetia, Finsch, Premier, Namaqualand, Kimberley and Koffiefontein. The balance is produced by small kimberlite, alluvial and shallow marine mines. This production is estimated to generate over US$ 650 million in revenue, as well as supporting a small cutting industry in South Africa.

1. LARGE KIMBERLITE MINES

1.1 Venetia

De Beers' Venetia mine opened in 1991 and is currently the largest producer of diamonds in South Africa. In 1995, 4.35 million carats were mined, or 45% of South African production. The mine is situated on the farm Venetia 103MS, 25 kilometres south of the intersection of the international borders of Botswana, Zimbabwe and South Africa, and 450 kilometres NNE of Johannesburg. The Venetia cluster comprises twelve Group I kimberlite bodies. The two largest pipes are currently being mined in a single open pit operation at an average grade of 136.4 cpht. The mine life is estimated at 20 years, although it is likely that other intrusions in the cluster might be mined in the future.

The main pipe is an irregular elongate body that strikes east-west and has maximum dimensions of 640 x 260 metres, covering 12.7 hectares at surface. The pipe dips at an angle of 82^{o} to the north and is intruded along the axis of a plunging anticline and follows the structure of the country rock. The country rock comprises gneiss, amphibolite and minor pegmatite of the cratonised Limpopo Mobile Belt. The pipe, dated at 500 Ma, consists largely of diatreme facies tuffisitic kimberlite breccia. Three relatively small hypabyssal facies intrusions occur close to the pipe margins. One of these pre-dates, and two post-date the main TKB intrusion. Numerous late-stage hypabyssal facies kimberlite dykes also occur.

1.2 Premier

The Premier kimberlite is situated on the farm Elandsfontein 480JR at the town of Cullinan, 25 kilometres north-east of Pretoria. It is the most important pipe in a cluster of twelve Group I kimberlites that includes the National, Schuller, Montrose and Franspoort pipes. Small alluvial deposits occur downstream of the kimberlites. The Mine was opened in 1902 and apart from brief closures between 1914 and 1916, and between 1932 and 1945, it has consistently been a major diamond producer with a high frequency of diamonds larger than ten carats. In 1995, it produced over 1.6 million carats or 18% of the South African production at an average grade of 44.6 cpht. The mine has produced about 300 stones of over 100 carats, and a quarter of all the plus 400 carat diamonds ever recovered in the world. Of the most famous are the 137 carat *Premier Rose*, cut from 353 carats, the *Niarchos* cut from 426 carats, and the 599 carat De Beers *Centenary diamond* in 1988. However, the most famous of all was the 3106 carat *Cullinan Diamond*, the largest gem diamond ever found, cut to form the 530 carat *Great Star of Africa* and 317 carat *Lesser Star of Africa* set in the Crown Jewels of Britain.

The pipe originally measured 32 hectares at surface, making it the largest diamondiferous kimberlite in South Africa. It has an elongate oval shape and comprises diatreme facies kimberlite to a depth of 550 metres, below which it grades into the root zone. The pipe intrudes fenitised quartzites of the Transvaal Sequence and is cut by a gabbro sill of 75 metres thick at a depth of 350 metres below surface. The pipe is dated at 1180 Ma and the sill at 1115 Ma. Premier is a complex body with three distinct kimberlite phases corresponding to three main phases of activity. The first phase produced a diatreme of “brown” tuffisitic kimberlite breccia (TKB) in the south-east, characterised by abundant shale and norite wall-rock inclusions. The second phase forms the main part of the pipe and comprises “grey” TKB characterised by an abundance of Waterberg quartzite, basement granite and gneiss inclusions. The third phase is a circular plug-like body comprised of “black” hypabyssal facies kimberlite, characterised by dark green pseudomorphs after olivine, intrusive into the western part of the pipe. Several later carbonatite dykes intrude, in a radial pattern, the black hypabyssal kimberlite and large blocks of “quartzite “floating reef” are present in the grey kimberlite in the middle of the pipe.

Alluvial diamonds, thought to be derived from kimberlites in the Premier cluster, have been recovered close to some of the pipes. On the farm Beynespoort 335JR, diamonds have been recovered from a gravel terrace above the Premiermynloop, a small stream draining the hill on which the Premier pipe is situated. Alluvial diamonds have also been recovered from a stream adjacent to the Franspoort kimberlite. No alluvial mining is recorded far from any of the pipes.

1.3 Finsch

The Finsch pipe is the most important kimberlite in a cluster that also includes the Peiserton pipe. Finsch was discovered in 1960 on the farm Brits in the Postmasburg District, by prospectors Finscham and Schwabel, 130 kilometres WNW of Kimberley. De Beers acquired a controlling interest in 1963, and in 1965 mining lease negotiations were concluded with the Department of Mines. The mine was acquired by De Beers in 1965 and changed from an open-pit to an underground operation in 1990. Up to 1995, an approximate total of 93 million carats had been produced at an average grade of 80 cpht. The average grade has varied considerably from year to year, due in large part to the presence of greater or lesser quantities of wall rock xenolith dilution. In 1995, a total of 1.72 million carats were produced at an average grade of 49.3 cpht.

The pipe is a Group II kimberlite dated at 118 Ma, intrusive into the Ghaap Plateau Dolomite Formation and the Kuruman member of the Asbestos Hills Ironstone Formation. At surface the pipe measured 17.9ha, making it the second largest economically important kimberlite in South Africa after Premier. The pipe is located on a precursor dyke set striking at approximately 50^{o} from north. The pipe is diatreme facies to the 680 metre level, and geological modelling suggests that the transition to the hypabyssal facies root zone does not occur above the 900 metre level. The geology is complex and some nine subsequent phases of intrusion have been recognised.. The presence of Karoo wall-rock xenoliths in the pipe proves that Karoo rocks existed on top of the Ghaap Plateau at the time of kimberlite emplacement, but have since been removed by erosion.

1.4 Kimberley

There are five pipes in the Kimberley Mines group, the De Beers, Kimberley, Bultfontein, Dutoitspan and Wesselton pipes. Presently, they are relatively minor contributors to the total South African diamond production with only Bultfontein, Dutoitspan and Wesselton in operation. The Kimberley Mine closed in 1914 and the De Beers Mine in 1990. In addition, the mine dumps are being re-processed by both De Beers and private operators. In 1995, the production totalled 593,630 carats. The original size and total production of the main Kimberley pipes and dumps are:

MINE	**SIZE (at surface)**	**PRODUCTION (to 1993)**
Kimberley	3.7 ha	32.7 million carats
Dutoitspan	10.6 ha	21.3 million carats
Bultfontein	9.7 ha	36.2 million carats
Wesselton	8.7 ha	33.6 million carats
De Beers	5.1 ha	36.4 million carats
Mine Dumps	-	11.4 million carats
TOTAL	**37.8 ha**	**171.6 million carats**

The pipes, dated between 84 and 87 Ma, intrude 90 to 120 metres of Dwyka Group sediments, overlain by porphyritic lavas of the Ventersdorp Supergroup. It is estimated that approximately 1400 metres of erosion has taken place since the emplacement of the pipes. At present day surface, all the pipes were in the diatreme zone, and the gradation into the root zone takes place at between 400 and 800 metres. Several different kimberlite types are present.

Other diamondiferous kimberlite intrusions in the Kimberley area include the Kamfersdam, Otto's Kopje and Belgravia pipes. Kamfersdam, situated on the farm Roodepan 70 seven kilometres north of Kimberley, was previously mined by De Beers, but closed in 1907. Otto's Kopje, on the Kimberley Townlands, was discovered in 1880, mined from 1891 to 1905 and again from 1911 to 1913. Although the grades from this mine were low, the diamond quality was high, and one exceptional diamond of 336 carats was recovered in 1896.

1.5 Koffiefontein

The Koffiefontein kimberlite pipe was discovered in 1870 shortly after the Jagersfontein pipe at the same time as the first discoveries at Kimberley. Due to the low grade, the Koffiefontein diggings received little attention and were exploited only on a small scale. The mine closed on several occasions due to economic factors and reopened most recently in 1987. To date, 7.3 million carats have been produced and the largest gem weighed 139 carats. The pipe is still mined by De Beers, and in 1995 produced 123,213 carats at an average grade of 6.9 cpht. It forms part of a cluster of Group I kimberlite pipes and dykes that intrude Dwyka shales and Karoo dolerites. Originally, it measured 10.3 hectares at surface and it is estimated that 1260 metres of the pipe have been eroded since emplacement at 90 Ma. The only other economically important pipe in this cluster is the Ebenhaezer pipe, adjacent to the Koffiefontein pipe, mined intermittently, but at an even lower grade.

2. SMALLER MINERALIZED KIMBERLITES IN SOUTH AFRICA

2.1 The Oaks

This mine comprises part of the Marnitz Kimberlite Provinc, discovered by De Beers in 1986. Three occurrences are known, situated on the farms The Oaks 153MR, Mooikloof 150MR and Dartmouth 27LR, in the Potgietersrus District approximately 350 kilometres due north of Johannesburg. The kimberlites are all of Group I type and are intrusive into quartzo-feldspathic and amphibolitic gneisses of the Limpopo Mobile Belt. The Oaks is a kimberlite pipe of approximately one hectare in size, has both hypabyssal and diatreme facies present and is currently the subject of a mine feasibility study. The Mooikloof kimberlite is a pipe of 2.5 hectares, but is exclusively hypabyssal facies with a very low diamond content and the Dartmouth body is a dyke.

2.2 The Zebediela Kimberlites

A number of kimberlite fissures, pipes and a blow were discovered by De Beers in the mid-1980s on farms in the Zebediela area 35km south-east of Potgietersrus. The occurrences have subsequently been prospected by SothernEra and comprise bodies known as Leopard Fissure, Sugarbird Fissure, Sugarbird Blow, Sugarbird Pass Pipe, M1 Pipe, M3 Kimberlite, Pruissen Pipe, Doornrivier Fissure, Kudu Pipe and Eland Fissure.

The M1 pipe, South Africa's latest diamond mine, was brought into production in August 1998 as a joint venture between De Beers (60%) and SouthernEra (40%). The Sugarbird Blow has been mined out yielding just over 78 000 carats with a carat value of US$105 while exploration continues elsewhere on the Klipspringer project. The Leopard Fissure is scheduled to be brought into production during 1999.

2.3 The Bellsbank -Barkly West Area

Several small diamondiferous Group I and Group II kimberlites occur in the Barkly West District to the north and north-west of Kimberley between Barkly West and Bellsbank. Some of these have been known since the turn of the century, and have been mined at various times in the past.

The Bellsbank fissures were discovered in 1952 by Danie de Bruyn on Farm 85 and are the most productive, currently mined by the companies TransHex, Messina Investments, Bellsbank Consolidated Diamond Mine and BKH Mining Services. They are Group II kimberlites dated at 119 Ma and intrude the dolomites of the Ghaap Plateau. The average grades vary from 25 to 70 cpht with a high proportion of gem quality stones.

Another economically mineralised Group II fissure system some 3.5 kilometres in length outcrops on the farms Sover 90, Doornkloof 89 and Mitchmanskraal 105 about 17 kilometres south-east of Bellsbank. Mining commenced in the 1940s and presently there are three operational mines, the Ardo (formerly Excelsior) and Du Plessis Section Mines, owned by Consolidated Mining Corporation and Carrig Diamonds, and the Sover-Doringkloof Mine owned by TransHex. The average grade of these mines is probably less than 20 cpht.

Frank Smith mine, owned by Good Hope Diamonds and Estates, lies two kilometres south-east of the Sover-Doornkloof fissure on Farm 105. It is a Group I kimberlite, comprising two pipes connected by a wide dyke, dated at 114 Ma. The total surface area is about 4.6 ha. It was acquired by Canadian company Diamond Fields Resources in 1994, who planned to increase annual production to 360,000 tonnes for a mine life of 20 years. At a reported grade of 5 cpht, this mine would produce approximately 18,000 carats of high quality diamonds annually.

Leicester and Balmoral are Group I kimberlite pipes on the farm Holpan 159, some 23 kilometres north-east of Barkly West. They were discovered in the early 1890's, and mined intermittently, with peak production during the 1960s. Leicester Mine was the subject of a recent feasibility study by Leicester Diamond Mines and Southern Era Resources, but currently neither is active. Despite the recovery of good quality diamonds, with some large stones reported, the grade was below 5 cpht, and the kimberlite was reported to be sub-economic.

Newlands is a Group II kimberlite complex comprising four small blows on a north-easterly striking fissure system on Farm 172, some 26 kilometres north-west of

Barkly West. Discovered in the early 1880s, the kimberlites were mined between 1903 and 1918, and again from 1956 to 1959. A total of only about 6500 carats were produced at an average grade of 7.5cpht. They have since been prospected by several parties, most recently by a South African consortium in 1994. No mining is currently taking place. Age determination indicates an emplacement age of 114 Ma.

Further small, poorly diamondiferous Group I and II dykes and pipes occur close to Barkly West. None are currently mined, but occurrences on the farms Good Hope 286, Bad Hope 285, Barkly West Commonage, and Holsdam 229 have historically been worked. A north-south trending dyke outcrops over the farms Saltpetrepan 127 and Roodelaagte 131 in the Herbert District. The dyke has been prospected on several occasions since its discovery near the beginning of the century, but no economic success is recorded. Prospecting work by Vanco NC Ltd. in 1964 suggested grades of up to 9 cpht. Two isolated diamondiferous Group II kimberlite occurrences are known in the Northern Cape Province. A dyke with a small “blow” outcrops on the banks of the Orange River on the farm Sanddrift 371 in the Hay district. The occurrence was discovered in 1905, and was mined on a small scale, producing 253 diamonds weighing a total of 36.5 carats. The small size of the diamonds led to the closure of the workings in 1907. In 1950, operations recommenced and some 300 diamonds were recovered at a grade of 75 cpht. The largest diamond weighed 18 carats, but the average stone size was too small to make the operation viable.

2.4 The Boshof Area

In the Boshof District, 75 kilometres east-north-east of Kimberley there is a cluster of Group II pipes and dykes, including the mines of Roberts Victor on the farm Damplaats 319, Blaauwbosch on the farm Catherine’s Fancy 831, and New Elands on the farm New Elands 949. In 1996, the Roberts Victor Mine (Rovic) was acquired by the Canadian company Botswana Diamondfields for US$4.3 million. This mine comprises two small pipes on a fissure, and in 1991 the reported average grade was 35 cpht with an average monthly production of 2800 carats. The Blaauwbosch Mine, a small elongate pipe of 0.1 ha, was reopened in 1965, but closed soon after despite reported grades of 18 cpht. The New Elands Mine, a kimberlite dyke with two small blows, has operated intermittently since 1912 but is currently dormant. The pipes reportedly grade at 10 cpht and the fissure at 30 cpht. A dyke, with a reported grade of 50 cpht, extends from this kimberlite onto the farm Zoet en Zuur 285 and has recently been mined. The Roberts Victor, Blaauwbosch and New Elands pipes have been dated at 128 Ma, 133 Ma and 127 Ma respectively.

2.5 Theunnissen and Virginia

Between Welkom and Theunnissen in the northern Free State diamondiferous kimberlites have been mined since 1910. There are two distinct areas, a Group II cluster to the north of Theunissen and a Group I cluster to the north of Virginia.

The Theunissen kimberlites form two lines of east-west trending dykes and blows intruding Beaufort Group sandstones. The southern line is the more important, and extends for 15 kilometres across the farms Diamant 25, Stieniesrust 218, Leeuwkop 277, Vergelegen 85, Monteleo 255, Erfbloem 12, Clewer 104, Wynandsfontein 53, and Mullersvlei 53. Star Diamonds has an operational mine on the farms Wynandsfontein and Clewer and Rex Diamond Corporation has a mine on the farms Stieniesrust, Vergelegen and Leeuwkop. The complex dykes are more important than the blows and lie within a fracture zone 100 metres wide, with an average width of 25 cm and a maximum of one metre. The northern line of kimberlites in the Theunissen cluster traverses the farms De Wilge 544, Driekoppies 422 and Deeldam 106. Two dykes are known, but no information on their diamond content is available.

The Virginia kimberlites also strike east-west, and traverse the President Steyn and Free State Saaiplaas gold mines. The only important intrusion is the Samada Mine on the farm Kaalvallei 12 between the two gold mines. It is a hypabyssal facies Group I kimberlite pipe, dated at 85 Ma, with a circular outcrop and a surface area of 1.9 ha. The mine is owned by the Consolidated Diamond Corporation, but closed in 1993 after reporting a substantial operating loss. Historical records suggest a grade of about 7 cpht.

2.6 The Loxtondal Cluster

The Loxtonsdal pipe, on the farm Loxtonsdal 409 in the Boshof District, is the most important intrusion in an ENE trending cluster of Group II kimberlites 20 kilometres north-east of Kimberley. The kimberlite is hypabyssal facies with an irregular dumbell shape and a surface area of one hectare. The pipe was first prospected in 1965, and early results by Loxton Exploration reported grades of 7 cpht. Subsequent work identified separate, high grade intrusions in the pipe. It is presently owned by Diamond Fields Resources, who reported grades of 100 cpht over 60% of the pipe. A dyke extension of this kimberlite is mined by Sonnenberg Diamonds on the farm Loxtondal 1610. The only other kimberlite to be mined in this cluster is a dyke on the farms Klein Leeuwkuil 1193 and Una 1431, 30 kilometres north-east of Kimberley. The dyke is 540 metres long and was mined between 1965 and 1988, reporting grades of up to 31 cpht.

2.7 Jagersfontein

The Jagersfontein pipe was the first diamondiferous kimberlite found in South Africa, and was mined from 1870 to 1931 and again from 1949 and 1971. It is the only economically important intrusion in the cluster of pipes and dykes, but is presently dormant. The original surface area of the pipe was about 12 hectares and it is a diatreme facies kimberlite, dated at 86 Ma, intrusive into Karroo shales and dolerite. It is estimated that the mined produced a total of 11 million carats. The mine was famous for producing diamonds of exceptional size and quality, including the *Excelsior* of 997.5 carats (the second largest gem diamond ever found), the *Jubilee* of 657 carats and other unnamed stones of 597.4 carats and 565.8 carats.

2.8 Lace and Voorspoed

The Lace and Voorspoed kimberlites occur on the respective farms of Ruby 691 and Voorspoed 2480 some 110 kilometres south-west of Johannesburg. They are the only economically important intrusions in a linear cluster of Group II kimberlite pipes and dykes. Lace, a low grade pipe that measures 1.6 hectares at surface, was discovered in 1896 and intermittently mined up to 1931, producing a total of less than 730,000 carats. Voorspoed, a larger pipe of 13 ha, was discovered in 1906, and mined until 1911 with a total production of less than one million carats. Almost half of the pipe has a large floating reef of Stormberg basalt. Both intrude Ecca shales of the Karoo Supergroup and Lace has been dated at 146 Ma. They are dormant mines owned by De Beers.

3. ALLUVIAL DEPOSITS

3.1 Lichtenburg-Ventersdorp to Schweizer Reneke Alluvial Deposits

Up to 1984, the total alluvial diamond from secondary deposits in the North-West Province was about 14.4 million carats. Small scale production persists today. The deposits lie within three geographical areas: The Lichtenburg field (67.8% of total production); the Ventersdorp field (18.6%) and the Schweizer-Reneke-Wolmaransstad-Bloemhof field (13.6%). The gravels near Schweizer-Reneke were worked most productively between 1910 and 1935, whereas production from the Lichtenburg gravels commenced in 1926.

In the Lichtenburg fields, the gravels overly dolomites of the Transvaal Supergroup and controversial genetic models having been proposed for the deposits. In the Schweizer-Reneke area there are three distinct gravel types: (a) the oldest “Rooikoppie” gravel, a chemically mature one to two metre thick, unsorted lateritized colluvial gravel unit, situated on hillcrests and the upper sections of hill slopes; (b) the younger upward fining “terrace-type” gravels of one to four metres thick occurring on the lower slopes of the present drainage valleys; and (c) the youngest “spruit-type” gravels, texturally and compositionally similar to the terrace-type gravels and occur in the current river valley floors. At Schweizer-Reneke, the per carat value of diamonds is much higher than Lichtenburg, suggesting that these diamonds have undergone some transport. No primary sources for the diamonds in any of these alluvial fields have been identified.

3.2 The Lower Vaal and Middle Orange River

The alluvial deposits of the Vaal River basin are almost exclusively preserved overlying lavas of the Ventersdorp Supergroup, where the Vaal, Orange, and Riet Rivers flow off the younger Karoo cover onto the basement. The deposits extend intermittently along the Vaal River from Windsorton in the north to Schmidtsdrift in the south. On the Orange River, they occur between Hopetown in the south and Douglas in the north, and continue intermittently for several tens of kilometres downstream of the Vaal-Orange confluence. A classic deposit is also developed on the Riet River on the farms Schutsekama 103 and Koppies Kraal 140. It is interesting to note that there is a downstream decrease in value per carat for each individual deposit. This reflects the decrease in average stone size, corresponding to the change from a proximal to distal facies in a braided river system. An example is the gravels at Waldeck’s Plant (Pniel 281) that are the proximal equivalent to those on Longlands 350, Delport’s Hope 355 and Than 280 in a mid-river alluvial fan.

Reliable production figures have never been compiled as these deposits were worked by thousands of individuals, over a very large area for over a century.

Production figures from the historical literature provide a minimum estimate of total production of 1,339,696 carats as follows:

DEPOSIT / AREA	CARATS
Windsorton (60m terraces)	130,000
Windsorton (0-20m terraces)	72,696
Nooitgedacht (Barkly West)	76,000
Droogeveldt	490,000
Waldeck's Plant gravel splay	530,000
Schutsekama gravel splay	30,000
Hopetown	11,000
TOTAL	**1,339,696**

3.3 Bushmanland

Alluvial diamond deposits are present above the western escarpment in Bushmanland and Namaqualand. The most successful mining operation away from the Orange River has been at Bosluispan on the farm Bosluis 238 some 90 kilometres south-south-west of Pofadder. Here, diamondiferous gravels occur at the base of the Koa Valley on an irregular and partially potholed bedrock of the Namaqualand Metamorphic Complex. The gravels are believed to be of Middle Miocene age, and deposited by a palaeo-Koa River, a tributary of the Orange River. Miocene and younger Plio-Pleistocene gravels are reported from the Sak River to the south of Brandvlei on the farms Paarde Kolk 243, Nel's Kop South 245, Zwart Kop 246, Piet Louw's Vlei 302, Dik Doorns Noord 30, Dik Doorns Suid 31 and Twee Rivier 84. These gravels rest on soft Karoo sediments and are of low grade. It is believed that the diamonds were reworked from pre-existing terraces associated with a "Karoo River" that flowed from the Kimberley region to the south-west across the Karoo to the modern Olifant's River mouth on the northern coast of the Western Cape. River capture diverted the drainages to the north into a proto-Orange River. Although economically of little importance, the deposits are of enormous interest, representing the only preserved remnants of the "missing link" between the primary sources and alluvial deposits on the craton to the east, and the rich alluvial and marine deposits on the west coast.

3.4 The Lower Orange River

The diamondiferous gravels of the Lower Orange River have been mined since 1966 and have a high intrinsic value, with the same high proportion of gem quality diamonds as the coastal deposits, but a larger average stone size. The main deposits, known as the Arriesdrift Gravel Formation, are located between Grasdrift and Bloeddrift in the Richtersveld and collectively comprise the Octha Mine operated by Trans Hex. Between 1973 and 1984, these deposits produced over 706,000 carats at an average grade of 3.6 cpht. They are of probable Miocene to Pleistocene age on the basis of mammalian fossils. Gravels are preserved on both sides of the Orange River in a series of elevated terraces, each distinguished by a marked drop in elevation resulting from a lowering of the erosional base level. The basal gravels comprise locally-derived, well-rounded to sub-angular cobble and boulder-sized clasts dominated by Nama quartzite. Minor quartz, schist, limestone, lava, jasper, agate and granite also occur with a heavy mineral suite of riebeckite, epidote, magnetite, haematite and almandine garnet. As in other alluvial deposits, the diamonds tend to be concentrated near the base of the gravel sequence particularly in association with bedrock irregularities such as potholes.

3.5 West Coast Onshore Deposits

The area between Kleinzee and Alexander Bay is characterised by a series of wave-cut terraces in a bedrock of Precambrian schist, phyllite and gneiss. Diamonds were discovered in 1925 by prospector Jack Carstens on the commonage south of Port Nolloth. Mining commenced in 1927, and in 1929 the Cape Coast Exploration Company (CCE) started operating on the farm Kleinzee. In 1941, De Beers purchased the share capital of CCE and several other properties and today owns much of the coastal strip over a distance of some 280 kilometres between the mouth of the Olifants River and Port Nolloth.

Diamond distribution correlates with the nature of the bedrock and sediment. Whilst isolated diamonds can occur virtually anywhere throughout the stratigraphic sequence, the basal gravel unit forms the main ore zone in most areas. Diamond distribution reflects the regional interaction between the northward transport of diamonds along the coast by littoral drift and the trapping of diamonds by various features such as coastal embayments. Locally, the bedrock morphology is a major control on diamond distribution with preferential concentration in bedrock trap sites.

Littoral drift, in the surf zone along the coast, is the result of the interaction between long-period south-westerly swells and powerful south-westerly winds that blow for much of the year. The currents can be reversed by a change in wind direction, resulting in the occurrence of a minor diamond distribution that extends south from the mouth of the Buffels River. However, the principal diamond distribution spreads north from the mouth of the Buffels River, with a northward decrease in average stone size. Immediately north of the Buffels River, the average stone size is 0.85 carats per stone, decreasing to 0.37 carats per stone at Oubeep, 30 kilometres to the north. A marked variation in average diamond concentration is also seen between the various raised beaches of which the most important is the 45 metre beach terrace. The variation is a function of diamond supply rate, suggesting that the 45 metre complex would correspond to a period when the Buffels River was flowing strongly and supplying diamonds to the surf zone at a relatively high rate. Four main mining areas are identified:

- The Koingnaas Complex between Mitchells and Somnaas Bays.
- The Buffels Inland Complex on terraces of the Buffels River inland of Kleinzee.
- The Buffels Marine Complex on the raised beaches north of the mouth of the Buffels River.
- The Alexander Bay area between Port Nolloth and the mouth of the Orange River.

The Koingnaas and Buffels Inland and Marine Complexes comprise De Beers' Namaqualand Mines Division. In 1995, these deposits produced 623,985 carats of diamonds.

3.5.1 Koingnaas Complex

There are two types of deposits at Koingnaas, a lower non-marine “Channel Clay” deposit, overlain by younger marine sediments preserved in broad bedrock depressions. The “Channel Clay” deposit comprises a series of steep gradient, contributory channel systems filled with texturally immature, compositionally mature basal gravels. The channels formed in response to a minor change in base level during Gondwana break-up, causing a period of headward scarp retreat into the existing peneplain that formed in an early phase of erosion during the Cretaceous. These represent the highest grade alluvial placers on the Namaqualand coastal plain. During the many transgressive and regressive post-Miocene cycles, some of the channel deposits were reworked by marine processes and the diamonds concentrated in the basal marine gravel in bedrock depressions. Marine packages are recognised at 90, 50 and 30 metres and recent emergent terraces comprising beaches at 3, 6 and 10metres.

3.5.2 Buffels Inland Complex

A series of diamondiferous gravel deposits occur along the lower course of the Buffels River below the Great Escarpment. The best preserved deposits comprise basal indurated gravels overlain by a series of sandstones, siltstones and clays that fill bedrock channels. The typical gravel deposits comprise well-rounded, clasts with grey, milky quartz clasts dominating. The channels are correlated with the Oligocene regression, and the aggradational infilling with the early to middle Miocene transgression.

3.5.3 Buffels Marine Complex

The Buffels Marine Complex covers the farms of Annex Kleinzee, Dreyers Pan, Karredoornvlei, Tweepad, and Oubeep and extends some 40 kilometres north from the mouth of the Buffels River. The bedrock competency influences both the diamond distribution and mining and varies with different metamorphic lithologies of the Stinkfontein Formation (Gariep Sequence). On the gneisses, there are deep potholes and gullies in which diamonds have concentrated. On the less competent foliated or calcretised lithologies, a more subdued bedrock profile has developed and good trap-sites are absent. Soft bedrock also creates mining problems, since the basal gravels may be diluted by over-mined bedrock. A steep-sided channel, 170 metres wide, on the farm Karreedoornvlei is infilled with carbonaceous lacustrine sediments dated as Neocomian by fossil pollen and spores. This deposit represents a remnant of a small syn-rift basin formed during the rift phase of Gondwana break-up.

A number of raised beaches of Pliocene to Pleistocene age occur within the Complex. They are locally divided into three terraces, the Upper (75-95 masl), Middle (30-65 masl) and Lower (10-30 masl). In places, the terraces are associated with well-defined wave-cut platforms and cliffs up to 20 metres high. Although the cliffs are regionally parallel to the modern coast, they are locally very irregular depending on the competency of the bedrock, with deep embayments and gullies, prominent headlands or small isolated stacks. Lithologically, the terraces comprise a basal transgressive unit of diamondiferous gravel overlain by sediments of nearshore, upper shoreface and foreshore facies. The fluvial channel and marine sediments are overlain by aeolian sands up to 25 metres in thickness.

3.5.4 Port Nolloth to Alexander Bay

The marine operations of the Alexander Bay Development Corporation (Alexcor) formerly known as the State Alluvial Diggings, are situated between Port Nolloth and the mouth of the Orange River. The first important discoveries were made at Alexander Bay in January 1927 on claims belonging to the geologist Hans Merensky. Within a few weeks, 12,500 carats of high quality diamonds were recovered and, in 1928, the State Alluvial Diggings were proclaimed at Alexander Bay to recover diamonds from beach placer deposits immediately south of the Orange River mouth. Until 1950, mining and prospecting was confined to an area extending five kilometres south of the Orange River estuary, but operations have gradually expanded southwards. Presently, both beach deposits and shallow marine deposits are mined.

4. MARINE DEPOSITS (WEST COAST OFFSHORE)

In 1959, a Texan marine engineer, Sammy Collins, recognised wave-cut platforms below modern sea-level with bedrock features similar to those developed onshore and the first offshore diamonds were found at Wolf Bay in Namibia, using a converted Royal Navy salvage tug, the “Emerson-K”. Production by the Marine Diamond Corporation (MDC) commenced in Namibia in 1962 and the success of this venture prompted exploration off the South African coast. In 1964, De Beers contracted Ocean Science and Engineering to perform a comprehensive evaluation of the shallow-water economic potential between the Olifants River in Namaqualand and Sandwich Harbour in Namibia. Based upon the results, De Beers exercised its option to become the majority shareholder in MDC in 1965. In early 1970, after the initial reconnaissance survey and mining stages, when MDC was the sole offshore operator, the mining concessions to the south of the Orange River were relinquished. The South African Government then subdivided the continental shelf to the south of the Orange River into twelve concessions, and later, in 1981, into the A, B, and C concessions, representing progressively deeper water from the nearshore intertidal zone and out onto the continental shelf. At present, the Government is in the process of awarding ultra-deep water, D concessions that extend from the continental shelf break (200 mbsl.) to the upper continental slope (500 mbsl.). In 1995, South African marine diamond production totalled 98,024 carats, an increase of 15% from 1994, attributed to the increased production from the deep marine concessions and likely to continue into the next century.

In Namibia the nearshore mining continued until 1971 when large-scale reserves were thought to be exhausted. MDC then assessed the potential for diamond deposits in deeper water on the middle continental shelf. In 1972, a key discovery was made when Boomer seismic data and vibra-cores of the upper 10 metres of sea floor sediment established the presence of clastic gravels at water depths of over 70 metres. Subsequent sampling thereof delineated a low-grade, patchy, but aerially extensive diamond deposit over tens of square kilometres. The realisation that new subsea mining technology would be required to exploit these deep water deposits led to the formation of the contracting and operating company De Beers Marine in 1983.

The geological history of these deposits, is complex, and involves the interaction of fluvial, marine and aeolian systems. Diamonds were introduced to the continental shelf via the Orange, Buffels, and Olifants Rivers and their precursors river systems draining the interior of southern Africa. During the Cretaceous to early Palaeogene, a southern ”Karoo River”, that included the Kimberley area in its catchment, introduced diamonds to the south western coast via the Olifants River exit. This system was subsequently captured by a northern “Kalahari River”, resulting in diamonds being introduced to the continental margin at the modern Orange River exit. The marine deposits are the product of repeated reworking of material derived from the hinterland by repeated marine regressions and transgressions over the continental shelf. Other than the control by marine and nearshore processes, in Namibia, aeolian processes have also been active during sub-aerial exposure during marine regressive events, corroborated by the presence of aeolian ventifacts in water depths exceeding 100 metres.

Cyclical sea-level movement without basin subsidence resulted in a condensed sequence of sea-floor sediments. Nearshore, the basal sediment sequence is similar to that found onshore, overlying Precambrian schist, phyllite and gneiss, suitable for the formation of classic diamond trapsites such as gulleys, potholes, cliffs and caves. In contrast, the bedrock topography on the middle shelf is more subtle, comprised of Cretaceous and Palaeogene sediments, reducing the frequency of trapsites. Here the ore gravel has abundant locally derived clasts of bedrock that were eroded during regressive and transgressive shoreface erosion. In general, the gravel clasts comprise variable quantities of quartz and quartzite cobbles as well as exotic clasts of epidote, agate, riebeckite, chalcedony, banded ironstone, and jasper. The latter are commonly associated with the Orange River and are thought to be derived from the Vaal/Orange river system between Kimberley and Prieska. The diamondiferous lag gravel is commonly overlain by a shell-rich Holocene transgressive lag, that fines upwards into a silt.

Current Exploration

In addition to the De Beers operations, licence holders now exploring and mining along the continental margin of southern Africa include BHP, Benco, Namco, Ocean Diamond Mining, Trans Hex and Alexcor. Their operations cover the entire continental shelf, extending to the 200 metres isobath. Following the recent award of ultra-deep water D concessions, exploration now extends to the 500 metres isobath on the upper part of the continental slope. At least one company has advocated the use of submarines for exploration and mining in this environment.

F. GLOSSARY OF TERMS

Aeolian processes - Wind processes.

Cluster - A group of individual kimberlite pipes or dykes ranging in numbers from several to fifty. Generally the cluster has a diameter of approximately 40 km. Several clusters form a field, whereas several fields are commonly referred to as a province.

Craton - The portion of the continent that has not been subjected to major deformation since the Paleozoic Era.

Dyke - A kimberlite which has intruded into the earth's crustal fractures. Dykes are generally linear, 1-3 m wide and extend for several kilometres along a linear strike.

Gabbro - A plutonic rock consisting mainly of Ca-plagioclase and clinopyroxene. An extrusive equivalent of basalt.

Gneiss - A high grade metamorphosed granite with a course texture of mainly biotite and plagioclase.

Holocene, Miocene, Oligocene, Pleistocene, Pliocene, Cretaceous - Geological time scales.

Hypabyssal - Defines an intrusive rock at depth intermediate between abyssal or plutonic and the surface (shallow depth). When applied to kimberlites, refers to dykes in the root zones of diatremes or to sills.

Isotherms - A line or surface connecting points of equal temperature.

Lamproite - Refers to a clan of peralkaline, typically ultrapotassic mafic to ultramafic rocks. Similar to kimberlites, they are hybrid rocks consisting of mixtures of primary magmatic constituents and upper mantle derived xenocrysts, including xenoliths.

Lithosphere - Solid outer portion of the earth including the crust and the portion of the upper mantle above the asthenosphere. Consists primarily of peridotite up to 175 km depth.

Macrocryst - A non-genetic term for relatively large (0.5 -10 mm), rounded to anhedral crystals set in kimberlite matrix.

Mantle - Zone of the earth below the crust and above the core (up to 3480 km). It is divided into the transition zone (up to 1000 km), the upper and lower mantle.

Metamorphic rock - A rock which has undergone physicochemical, mineralogical and structural changes when subjected to high temperature and pressure at depth within the earth's crust.

Metasomatism - Replacement of minerals by different ones within a rock by the slow action of percolating fluids.

Microdiamond – A diamond less than 0.5 mm in daimeter**.**

Mobile Belt - A long, narrow crustal region characterised by present or past tectonic activity.
Peridotite - A plutonic rock consisting mainly of olivine and pyroxene.

Phenocryst - Crystal set in kimberlite matrix that have crystallised from the host magma.

Phyllite - A metamorphosed rock of grade intermediate between slate and schist

Precambrian - The time preceding the Cambrian. It ranges from 4.7 Ga to 590 Ma. Generally associated with the time of the formation of the cratons.

Schist - A metamorphosed shale with layered texture due to muscovite crystals
These are geological time scales

Ventifacts - Stones shaped by wind in a desert area.

Xenocryst - A crystal foreign to the host magma and picked up from the wall rocks en route from melting to crystallization site. Xenocrysts may be derived from the mantle, or shallow depths.

Xenolith - A foreign inclusion in an igneous rock.