Echantillonnage des gisements kimberlitiques à partir de microdiamants. Application à l'estimation des ressources recupérables.

Sampling and Estimation of Diamond Content in Kimberlite based on Microdiamonds.

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August 2013

Declaration

I declare that this thesis is my own work, except where otherwise acknowledged or referenced in the text. It is being submitted for the Degree of Doctor of Philosophy at the Ecole des Mines des Paris. It has not been submitted before for any other degree or examination at any other university.

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J.J. Ferreira

August 2013

Dedicated to my family

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During the years with De Beers and Anglo American, I could not have had more opportunities to grow into and experience the science and art of mineral resource evaluation, than under the leadership of Dr. Wynand Kleingeld.

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Préambule

L'objet de ce travail est l'estimation des diamants de gisements kimberlitiques à partir d'information fournie par des microéchantillons.

Cette estimation repose traditionnellement sur les pierres commercialisables de plus d 0.5mm, sans tenir compte des petites pierres qui sont de loin les plus abondantes et qui finissent au rebut stérile. Le problème est la taille des échantillons. Ils doivent être assez grands pour contenir un nombre suffisant de telles pierres en vue de l'estimation. Pour réduire la taille des échantillons, l'idée est d'abaisser le seuil de récupération des pierres. A cette fin, des techniques spécifiques ont été mises au point (dissolution de la kimberlite à l'acide), permettant de récupérer toutes les pierres de plus de 75 microns (0.0000018carat). A partir de ces nouvelles données, des procédures d'estimation ont été élaborées au fil des ans pour déboucher sur un protocole mature.

Du point de vue traitement des données, le point le plus délicat est l'estimation de la loi des pierres commercialisables à partir de pierres essentiellement petites. La solution proposée repose sur une hypothèse de lognormalité de la taille des pierres, hypothèse pertinente dans la totalité des gisements primaires de diamants étudiés. L'estimation des paramètres doit tenir compte du nombre limité des données et de leur biais, dû à la perte inévitable des pierres les plus petites au cours du traitement des échantillons. Elle se fait selon une procédure itérative, une phase de simulation d'une population de pierres selon la valeur courante des paramètres alternant avec une phase d'ajustement des paramètres destinée à mieux restituer la loi des données tronquées observées. Elle permet la prise en compte simultanée de plusieurs jeux de données récupérées à différents niveaux de troncature correspondant à differents modes d'échantillonnage. Cette procédure met en jeu une représentation graphique comparée des lois expérimentale et simulée, mettant ainsi en évidence la quantité de pierres perdues.

Preamble

This research deals with diamond content estimation in kimberlite based on information obtained from microdiamond sampling.

In spite of the abundance of diamonds smaller than 0.5mm square mesh the conventional approach of estimating diamond content is based on information derived from stones in the +0.5mm size fraction. While large samples are required to ensure recovery of sufficient numbers of diamonds for evaluation the largest number is therefore discarded as treatment tailings.

As far back as the 1960's this inspired the approach to lower the bottom screen aperture in order to recover microdiamonds, and was accompanied by the introduction of recovery methodology based on acid dissolution.

As a consequence the required sample size is smaller, bringing along many practical advantages. The research deals with estimation of the weight of diamonds (diamond content) in kimberlite, based on information obtained from microdiamond sampling to a bottom screen diameter as low as 0.075 mm square mesh (~0.0000018 carats).

Determination of the diamond size distribution has always been a challenge when estimating deposit diamond content. The method proposed in the research is based on the assumption of lognormality, which is in line with experience at all primary deposits.

Over the years special techniques of estimating deposit diamond content have been developed and in this research have 'matured' into a proper sampling and estimation approach, taking cognisance of the fact that sampling is partially 'flawed' due to inevitable losses of diamonds during sample treatment. Some smaller diamonds are lost when they pass through the bottom cut-off screen used during diamond recovery, when according to their weight they should actually be recovered. Other losses of small diamonds occur when they remain locked in host rock particles and are discarded along with non-diamond bearing material.

Modelling of diamond content is performed by means of an iterative process of simulating diamonds as distributed in their in situ state, followed by emulating recovery effects to reproduce a representative sample.

Inclusion of multiple sets of data collected at different truncation levels by means of different sampling methods is allowed and the procedure uses graphic representations of diamond size and concentration to compare simulated and sampled diamonds. During the process simulation parameters are adjusted until the exact sampling results are reproduced, at the same time exposing what is being lost during recovery.

It is common in the Industry to fit a size distribution model to the actual recovered size distribution, regardless of the size of the sample considered and often unaware of the effects of applying a bottom cut-off in diamond recovery. In this research modelling is focused on obtaining a statistical model for the in situ size distribution, unaffected by processing, making it possible to determine recoverable diamond content at any given truncation level.

Glossary

1. ALIGNMENT FACTOR

This is the ratio of recovered carats to in situ carats in a size class. Application of alignment factors to in situ resource carats (stones) provides estimated recoverable resource carats (stones) per size class.

2. BOTTOM CUT-OFF

Setting a bottom screen size or bottom cut-off size, gets rid of small, uneconomic diamonds during the recovery process. However, due to their different shapes some smaller diamonds may still be recovered, while others that should be recovered are screened away. As a consequence diamond frequencies in the bottom size classes are affected and do not reflect in situ diamond occurrence accurately.

3. BOTTOM TRUNCATION

Size classes affected by the bottom cut-off procedure are eliminated from certain modelling procedures by truncation. Bottom truncation always takes place at or above bottom cut-off.

4. CLASS BREAKDOWN

When a parcel of diamonds is sieved the combination of class carats (or stones) for all the sieve classes is referred to as the parcel “breakdown”.

5. CRITICAL DIAMOND WEIGHT or SIZE

Diamonds are sized by sieve aperture with weight and stone shape determining the destiny of a diamond in the sieving system. Critical diamond weight is the class weight limit between two consecutive size classes. It is defined as the weight of diamond that will pass through the sieve or stay on top with equal probability. Alternatively, it is the weight of diamond that has 50% chance of staying on top of the screen. Since it depends on size as well as shape it is recommended that a set of critical diamond weights be determined for each new diamond assortment.

6. DIAMOND ASSORTMENT

This is the specific combination of colour, shape, intensity and size of diamonds from a deposit or from a domain within a deposit.

7. DIAMOND CONCENTRATION

The number of stones per unit weight of ore. In the case of microdiamond sampling, concentration is expressed as stones per 20kg or stones per kg. Generally it may also be expressed as stones per tonne when appropriate, but always with the bottom screen size to be used for diamond recovery specified.

8. DIAMOND CONTENT

The total weight of diamonds contained in a domain, which could be a sample or the entire deposit, expressed in carats (5 carats = 1gram) above the bottom screen cut-off size in use for diamond recovery.

9. DIAMOND GRADE

The weight of diamonds per unit weight of ore, typically expressed as carats per tonne (cpt) or carats per 100 tonnes (cpht, 1 tonne = 1000kg). During sampling and evaluation diamond grade may also be expressed per unit volume as carats per cubic meter (cts/m3), always specified with the bottom screen size aperture to be used for diamond recovery.

10. DIAMOND LIBERATION

Diamonds are naturally contained in hard kimberlite rock. Diamond liberation is achieved by means of a treatment process that involves crushing the host rock to specific aperture sizes and separating diamonds and denser rock particles as concentrate. Less dense material that most likely does not contain diamonds is discarded as tailings. Large tailings particles may still contain small diamonds and are crushed in a secondary process to smaller aperture sizes for diamond recovery. If cost effective, the process may be repeated at yet smaller crusher aperture size.

11. DIAMOND LOCKUP

Diamond lockup occurs when diamonds are not liberated during the treatment process. When a particle contains a diamond so small that diamond-to-particle weight contribution is too small to be separated as concentrate, the diamond remains locked in the particle.

12. DIAMOND PARCEL

A collection of diamonds grouped together form a diamond parcel and may be diamonds that fully or partially represent recovery from production or sampling.

13. DIAMOND SIEVING

The large number of stones recovered during an ordinary production period prohibits reporting of results in the form of a listing of individual diamonds. Stones are sieved into standard size sieve classes and weighed and valued by size class. The sieve size class system of the De Beers Trading Company and the Antwerp sieve size classes are most frequently used.

14. DOMAIN /LITHO-FACIES

A kimberlite deposit may be composed of material deposited by more than one volcanic event forming multiple families of kimberlite in the deposit. Kimberlite within a deposit may display different geological characteristics containing different diamond assortments, described as different kimberlite facies. The research is based on the premise that a deposit is composed of different domains, each having unique lithology and diamond content characteristics. Diamond content and value are consistently assessed by domain, whether it is a litho-facies or a subdivision of a litho-facies.

15. KIMBERLITE

A 'hybrid' rock composed of fragments of Peridotite and Eclogite transported from beneath the deep crust in the upper mantle of the earth. It is a volcanic rock that is best known for its diamond potential. Its naming is related to the town of Kimberley in South Africa, where the ‘Hope’ diamond (83.5-carat) was discovered in 1871.

16. KIMBERLITE PIPE

This is a vertical structure in the earth's crust and the most important source of primary diamonds. The consensus on kimberlites is that they are formed deep within the mantle at depths between 150 and 450 km and they erupt rapidly and violently. [8]

17. LOG-CONCENTRATION LOG-SIZE CURVE (LC-curve)
Diamond concentration plotted against diamond size on log scales, with concentration expressed as stones per weight unit per unit class interval and with size represented by the average stone size per size class. The curve is used as modelling tool to obtain total or in situ diamond content.

18. LOG-PROBABILITY CURVE (LP-curve)
The percentage cumulative more than frequency distribution in the size frequency table, expressed as probability. The Gaussian inverse of this probability is plotted against the log of the lower diamond size class limit. [$(G^{-1}\left(1-F(x)\right)$ *versus* $\ln(\mathrm{x}))$]. If the size distribution is lognormal the LP-curve is linear.

19. MACRODIAMOND
A stone that does not pass through a 0.5mm square mesh screen is defined as a macrodiamond. It can be present in microdiamond sample recovery and its occurrence in microdiamond sampling results is for obvious reasons specially mentioned when microdiamond sampling results are quoted.

20. MICRODIAMOND
A microdiamond is defined as a diamond passing through 0.5mm square mesh. [7] The definition is based on size and not weight and was initially defined as diamonds that would pass through the lowest commercial screen size at 1mm. Microdiamonds were also known as 'fine' diamonds, but this terminology was abandoned to eliminate confusion, as commercial diamond size fractions are also referred to as 'fines', 'middles' and 'coarse'.

21. MODIFYING FACTOR
Factors applied to convert resources to reserves. Factorisation that may be required in order to account for process inefficiencies during production treatment, which may differ from sample treatment processes that were used to create the resource.

22. ORE DRESSING
The first stages of treatment process for the extraction of mineral (diamond) from its host rock.

23. PRIMARY DIAMOND DEPOSIT
A kimberlite pipe is a primary diamond deposit, as it contains diamonds in the host rock of their primary origin. If kimberlite erodes and deposits its diamonds in gravel beds in rivers or in the ocean, then a SECONDARY DIAMOND deposit is formed.

24. RECOVERABLE DIAMOND GRADE/CONTENT
Diamond grade or diamond content modified to exclude diamonds that will not be recovered due to diamond lockup and screening losses in the bottom size classes, with bottom screen size to be used for diamond recovery specified.

25. SIZE FREQUENCY DISTRIBUTION (SFD)
The statistical distribution of diamonds into size classes is presented in tabular form as a size frequency distribution.

26. TYPICAL DIAMOND PARCEL
Any collection of diamonds grouped together form a diamond parcel. In the context of this thesis a typical parcel represents exactly what may be expected to be in a large production- or sampling parcel from a source, in terms of diamond size distribution and diamond concentration.

1 Introduction

1.1 Background

Diamonds are considered to be a rare mineral and the particulate nature of diamonds puts the evaluation of diamond deposits in a unique category of mineral resource evaluation.

The unique size distribution with a much more abundant presence of small stones in kimberlite material opens the door to smaller samples and a slightly less hostile environment for diamond content estimation. The research is focused on diamond content estimation based on microdiamond sampling from primary kimberlite deposits. (Secondary deposits have been addressed by Prins. [48])

Recovery of microdiamonds was instigated by Dr L Murray and commenced in 1965 at the Anglo American Research Laboratories in Johannesburg (AARL). Treatment of 20kg samples started in 1969 and was carried out on a regular basis from 1971. Attempts to predict macro grade on the basis of microdiamonds did not produce good results initially and the application was regarded suitable only to distinguish between diamondiferous and non-diamondiferous material

Between 1971 and 1988 an extensive data base was created by AARL. At the Kimberley Acid Lab (KAL) a large amount of sampling material had been treated and the results were added to the AARL data base. At this time it was argued that macro grade prediction could be improved when microdiamond occurrence is classified into high or low microdiamond producers.[1]

In 1973 it was reported that the 'weight-frequency' distribution of 'fine diamonds' (microdiamonds) in kimberlite usually follows a lognormal distribution, but that the process of de-sliming kimberlite residues through 200 mesh (0.212mm) had the unfortunate effect of changing the shape of the distribution in the finer size classes. Already at that stage the weight-frequency distribution of diamonds was plotted on logarithmic probability paper.

It was reported that the distribution is lognormal, with strong indications that a simple relationship could exist between the concentration of fine diamonds and the overall grade of the kimberlite - '*provided the diamonds are of a size grade enabling true representativity*'. It was argued that such a

[1] Kleinjan L, Reappraisal of Fine diamond data, July 1988 (AARL Report)

relationship would be '*grossly affected by contamination of kimberlite by foreign matter*'[2]. The use of the log-concentration versus log-size representation (or LC-curve) for diamond samples was already established.

During those years the recovery process was continuously being improved. A report was produced stating that it was proved that a direct relationship exists between the concentration of fine diamonds and the diamonds recovered by mining, being a '*valuable practical method for the determination of the presence of diamond and the payability of any kimberlite mass by simple and inexpensive means*'[3].

The author's first encounter with the application of microdiamonds was in 1981, when he joined De Beers Consolidated Mines in Kimberley, South Africa. It was a highly sensitive subject and everything relating to the topic was confidential. Work carried out at the time was mostly aimed at assessing diamond potential in new discoveries.

Material was being collected from operating mines with the obvious view of testing the theory with kimberlite for which macrodiamonds were readily available and with known diamond content.

In the public domain microdiamond work was reported to have been carried out on material from the Argyle Deposit in Australia [2]. Boxer and Deaken recognised a discrepancy zone in depicting log-stone frequency versus log stone size in the size range between 0.01 and 0.1 carat, showing linear and quadratic relationships for micro- and macrodiamonds.

The use of a second degree polynomial to approximate total diamond content was based on the lognormal nature of statistical distribution of diamond weights [54]. This characteristic of diamond weights in a representative diamond parcel has generally been observed and is used at operating mines to audit the treatment and recovery of diamonds.

Rombouts made use of a plot of cumulative grade versus microdiamond size to obtain an extreme value graph [51]. In collaboration with others he continued to apply Extreme Value Theory to diamond size and value analysis [6] and [4]. They focused on actual diamond parcels not on the in situ content as done in this thesis.

Caers published his PhD thesis in 1996 on the statistical and geostatistical valuation of diamond deposits, providing extensive coverage of new methods for valuation of primary and secondary diamond sources [5] . His work focuses mainly on macrodiamonds. He mentions that the topic of estimating macrodiamond content from microdiamonds was addressed while working on the thesis, but does not present any results.

Research at De Beers indicated preference for the representation of diamond concentration versus diamond size. Estimation was based on graphic representations of what was called the 'diamond content curve' and results were promising enough to justify the construction of the Kimberley Acid Laboratory.

The lognormal nature of the distribution of diamond weights implies that the Log-Concentration curve (LC-curve) is a second degree polynomial. An advantage of the LC-curve representation is that it allows micro- and macrodiamonds from different sampling campaigns to be combined for diamond content modelling and is therefore preferred above cumulative plots and Extreme Value Theory.

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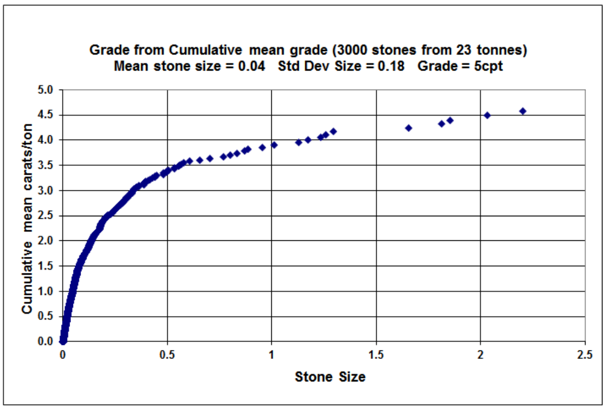
[2] Glatthaar GW. Weight-frequency distribution of microscopic diamonds in kimberlite, July 1973 (AARL Report).

[3] Garvey O and Glatthaar GW. Development of the treatment process and examination of kimberlite for the presence of microscopic diamonds, circa 1980 (AARL Report).

Figure 1-1 depicts plots for cumulative mean grade (left) and the LC-curve (right) based on individual stone weights and sieved diamond frequencies respectively.



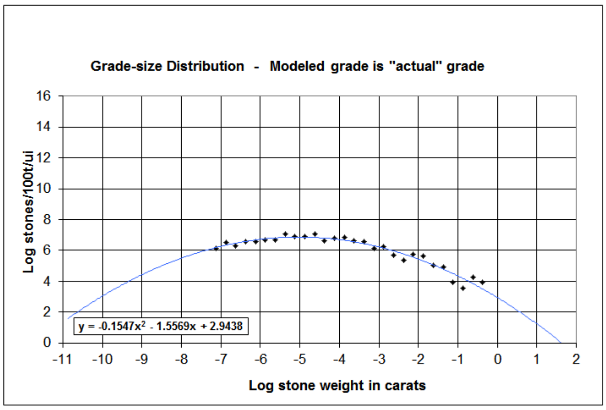


Figure 1-1: Two methods of representing diamond content. The lognormal approach is preferred as the 2nd degree polynomial is easily modelled and allows diamond content modelling based on small samples. The curve on the right depicts log concentration versus log size (LC-curve) and may also be referred to as the 'diamond content' curve. The curve on the left represents cumulative mean grade with diamond size and is not used in this thesis.

A microdiamond data base was steadily growing as it was clear that there was potential to use microdiamond sampling to estimate macrodiamond potential. Sampling results from all the Southern African mines and many deposits worldwide were considered (such as [46]) for microdiamond modelling purposes by [4]M.M. Oosterveld until and after his retirement in 1997.

In 2003 a research team was created by De Beers specifically with the aim of delivering techniques to shorten the time between discovery and mining or walking away from a deposit. One section of the research was concerned with sampling and estimation of diamond content in kimberlite deposits with special focus on microdiamonds.

The work has since culminated in a methodology that allows microdiamonds to be used as a valuable tool in sampling for diamond content estimation, from early reconnaissance to advanced feasibility stages of diamond resource evaluation.

1.2 This research

Microdiamonds are believed to come from a different diamond population in the mantle and for a long time it was believed that it would not be possible to extend diamond content properties based on diamonds from the microdiamond size range to diamond content in the macro size range.

This argument has been persistently posed even in the face of microdiamonds merely being defined on the basis of their size. However, continued application of the methodology and the obvious rewards by doing so has led to wide acceptance of the idea of microdiamond sampling for diamond content.

[4] Oosterveld, M.M. played a major role in establishing and developing the application of microdiamond sampling in estimating diamond content in primary diamond deposits. The highly confidential nature of the work restricted the exposure he deserved in this field and this text as a whole must be seen as a credit to his work.

Luc Rombouts, Tinus Oosterveld, Andy Davey, Boxer, Deakin, Len Kleinjan and Owen Garvey are names in the industry who have been using microdiamonds to predict macrodiamond grade, in spite of what many experts have been saying. Much of the work was highly confidential[5].

Estimation was based on a graphic presentation of what was known as the diamond content curve, but denoted the LC-curve in this thesis. Diamond content was estimated by comparing LC-curves for new discoveries with those constructed for known producers[6].

The Anglo American Research Laboratory and the Kimberley Acid Laboratories were two facilities used by De Beers to recover diamonds by means of acid digestion.

Material was selected for microdiamond recovery in order to enable diamond content modelling. Deposit material most likely to contain diamonds was selected for treatment to maximise stone recovery, therefore much of the oldest sampling databases contain sufficient information for diamond size analysis, but could be misleading with respect to diamond concentration.

An incident is recollected where high diamond grade was estimated for a highly diluted kimberlite in Canada, without any of the sampling records referring to the high levels of dilution observed in drill core that was typical for this kimberlite. Other discrepancies between microdiamond and macrodiamond grade estimates occurred due to recovery issues and small sample variation, which had to be dealt with swiftly to restore confidence in the methodology [17].

The arrival of spreadsheet technology made it easier to do graphic representation and the 2nd degree polynomial proved to be applicable in every case examined, but often only when selected points on the sample LC-plot were eliminated. Rules were made about the minimum number of stones per size class required for reasonable LC modelling (the presence of at least ten stones in at least five consecutive size classes) and the minimum amount of sampling material (400kg) to be collected when sampling new sources[7].

In 1997 a personal turning point came when a decision was made to treat more microdiamond samples from the Victor kimberlite in Canada. The decision was made to do limited 6-inch percussion drilling for macrodiamond recovery from this pipe, based almost solely on promising geochemistry results. Microdiamond sampling consistently yielded low stone counts and the associated non-typical LC-curve suggested low interest in the pipe.

Percussion sampling produced 96 macrodiamonds with combined weight of 6.99 carats and results were combined and plotted with existing microdiamond results on one LC-graph. An unusually coarse diamond concentration profile was observed and grade was estimated at more than 30cpht. The macrodiamonds were sent to Harry Oppenheimer House in Kimberley for diamond valuation[8] [19].

Individual stone values were not customarily provided, but were requested and informally received. The values were grouped by size class and an average class value calculated. Combined with the size distribution derived from 113 microdiamonds from drill core and the 96 macrodiamonds from percussion drilling, an average diamond value in excess of US$200 was estimated, based on 6.99 carats.[9] [22]

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[5] Author's experience at De Beers

[6] Oosterveld M.M., Diamond content curves for known Southern African producers, 1993, De Beers report

[7] Ferreira J.J., A perspective on macrodiamond grade estimation based on microdiamond frequencies, 1995, De Beers report

[8] Ferreira J.J., Attawapiskat grade estimate, 1997, De Beers report.

[9] Ferreira J.J. , Victor pipe estimates, 1998, De Beers report.

It was possible to model diamond size on the basis of the 96 macrodiamonds only, but the presence of the 113 microdiamonds confirmed the LC-curve for the coarse diamond size distribution. Observation of this coarse size distribution and the correlation between micro- and macrodiamonds gave impetus to the development and application of the methodology. [43]

With the intensified use of microdiamonds for diamond content estimation and the potential for wide application of the methodology, correct sampling procedures became a priority. Dr Matthew Field designed a sampling protocol in Kimberley and this was revised in 2004. It was again revised in 2006 in view of new findings from sampling planned for the Gacho Kue pipes in Canada and resource extension programs for the major Southern African mines.

The effect of kimberlite dilution as being directly related to diamond content was introduced by Dr Matthew Field and became one of the key variables to be recorded during microdiamond sampling [24].

In 2011 Dr Lantuéjoul introduced a theoretical approach to estimate diamond content based on microdiamonds using the Cox Process and incorporating the truncation principles used in this thesis [37].

Being able to access the more abundant size fraction of a diamond assortment provides real benefits, some of which are listed as follows:

- The abundance of small stones allows the use of much smaller samples.
- Small samples are easy to handle, transport and store.
- Microdiamond samples are collected by visual inspection of drill core.
- Core drilling is cheaper than large diameter drilling and the possibility of drilling angled holes allows access to zones that would otherwise remain excluded from the sampling data base.
- Treatment and recovery takes place at authenticated laboratories and eliminates further overhead costs associated with sample treatment.
- Although the cost of recovering microdiamonds by means of acid digestion or caustic fusion is high, substantial saving is made with core drilling for microdiamond sampling instead of large diameter drilling (ldd) for macrodiamonds.
- Microdiamonds have no commercial value and it is not necessary to embark on an expensive campaign to secure diamonds.
- As the small stones hold no value and are easily stored they can be kept indefinitely.
- Microdiamond sampling allows the development of a diamond size distribution model even before the first macrodiamond sample is collected. Combination of the size distribution model with the values of a relatively small number of macrodiamonds provides a valuable first estimate of average diamond value for a deposit early in its evaluation sequence.

1.3 Diamond Size

Continuity in the diamond size distribution is illustrated in Figure 1-2, which shows cumulative logarithmic probability curves (LP-curves) [60] for 12 microdiamond samples from a geological domain in a Canadian diamond deposit.

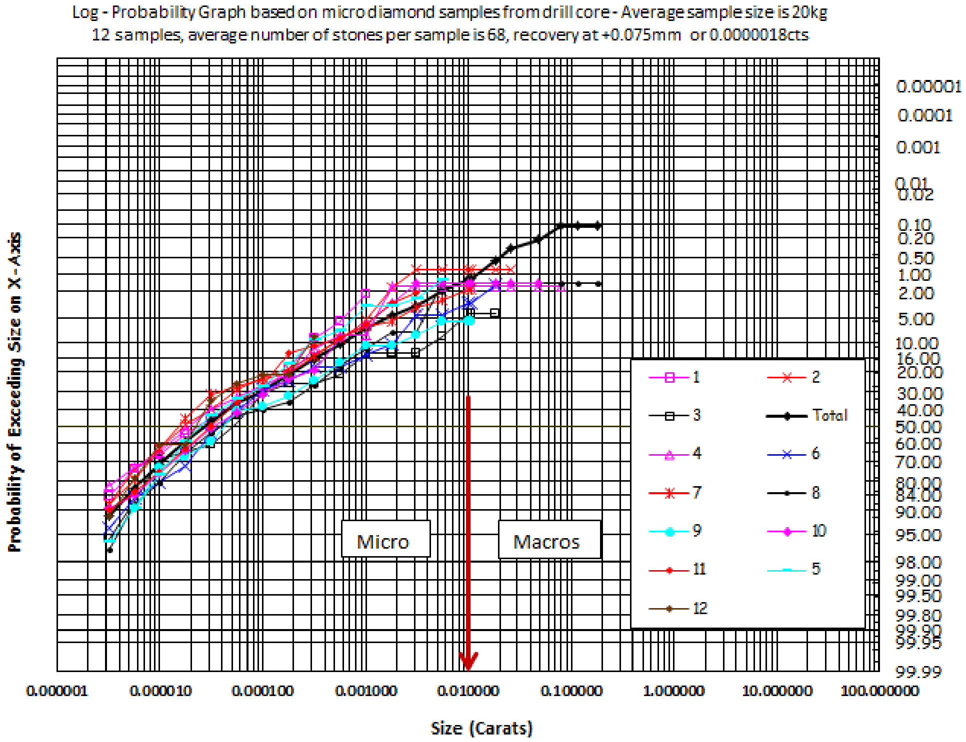

Figure 1-2: LP-graphs demonstrating continuity of distribution of diamond weight

The red arrow indicates the point which approximates the upper limit for microdiamond weights, clearly with no discontinuity in any of the sample curves. This is a typical observation, forming the basis for the use of microdiamonds for diamond content estimation.

The combined sample indicated by the black curve contains a large number of stones. Consequently its curve is more continuous and reaches well into the macrodiamond size range. If more samples are added, it will reach even further into the macrodiamond size range.

The use of the lognormal distribution for diamond weight has been used extensively [52] and is established in auditing procedures for commercial diamond recovery in the diamond industry. It plays an important role in this research and represents diamond assortments that include diamonds from far below commercial bottom truncation sizes.

Recovery of microdiamonds is achieved by means of acid digestion and caustic fusion methods and the high concentration of small stones holds many rewards with respect to sampling and estimation of diamond content.

1.4 Diamond concentration

Diamonds have a particulate nature and size plays an important role as larger stones generally tend to be more valuable.

Diamond content is derived from a combination of the distribution of diamonds in size classes and diamond concentration. The LC-curve is a graphic representation exposing the distribution of diamond concentration with diamond size. An example is shown in Figure 1-3.

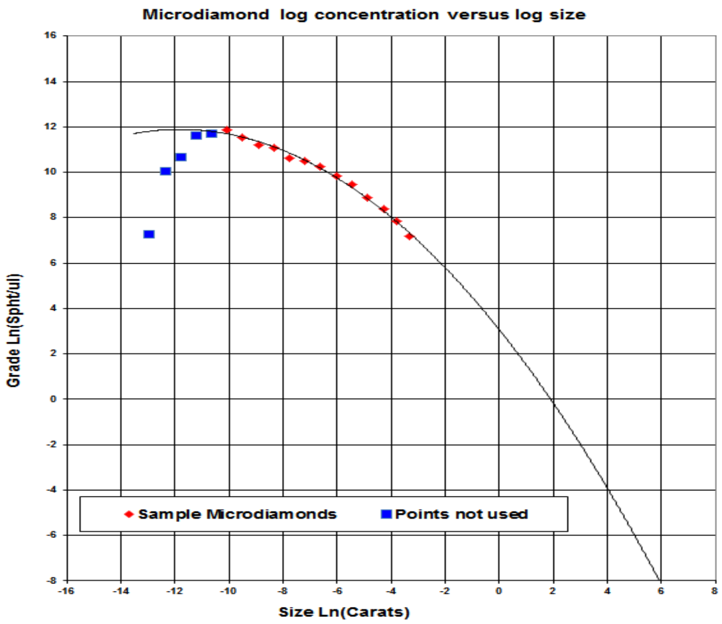

Figure 1-3: Representation of diamond content by means of LC-curve. The example shows a plot of microdiamond recovery with the bottom five size classes affected by recovery losses that normally occur during sampling. These size classes are not suitable to be used for diamond size modelling.

Sampling results are expressed as diamond concentration per size class in terms of the number of stones per tonne (or per 100 tonnes) per unit size class interval. The associated LC-curve is a 2nd degree polynomial and is shown to intersect the sample points not affected by bottom cut-off losses.

Until late in the 1990's diamond content estimates were based on the LC-curve without first modelling diamond size. The estimation process was highly subjective and estimates varied substantially between different analysts and even between different attempts by the same analyst.

This research transformed microdiamond sampling and diamond content estimation into an iterative modelling procedure. The iterative procedure first focuses on modelling diamond size, then on diamond content via a combination of diamond concentration and diamond size.

The LC-curve in Figure 1-3 represents diamond concentration on the basis of microdiamond sampling results and is used to derive diamond content above any appropriately selected diamond size.

1.5 Diamond Content

The LP- and LC-curves introduced in the previous sections (Figure 1-2 and Figure 1-3) play a fundamental role in diamond content estimation.

Every diamond pipe has a unique diamond assortment and geological composition and the art of diamond content estimation is to find statistical models for diamond size and diamond concentration. Diamond content is derived from a combination of the diamond size distribution model and a model for diamond concentration.

The continuous nature of the distribution of diamond size provides the option of selecting an appropriate size range to be sampled from. Microdiamond sampling is focused on the size range above 0.075mm, while diamonds from size ranges above 0.5mm are recovered during conventional sampling and production.

Diamond size is modelled on the basis of the size distribution of microdiamonds in the form of the LP-curve.

Diamond concentration is modelled on the basis of subsample stone concentrations. If enough subsamples are available a statistical distribution is fitted to the concentration histogram.

Under the assumption of a continuous size distribution, a system has been developed to generate a typical diamond parcel with given diamond size and concentration distributions. The size and concentration models are used to generate a large sample in the form of, say 1million microdiamond subsamples. If the models are realistic the typical parcel should accurately reflect deposit diamond content in accordance with sampling data.

In the initial sampling stages the only data available almost always comprises microdiamonds recovered from thin core subsamples.

Continued interest in an occurrence eventually involves macrodiamonds to confirm the microdiamond size model and to provide diamond values for revenue modelling.

In the final estimation stages diamond content is established locally within domains in the deposit to allow mine planning exercises.

1.6 Sampling

The size of diamond deposits and the magnitude of sampling regimes inevitably require sampling to be done in phases. Initial interest is in the nature of the kimberlite deposit, mainly whether it is diamondiferous, and is immediately followed by an interest in diamond content. Further interest extends towards more detailed zonal diamond content in collaboration with developing a geological model for the deposit.

If diamond content suggests potential economic viability then diamond value becomes the next variable of interest and sampling is focused on recovering diamonds from the commercial size range. If economic viability is still indicated then sampling intensifies to provide information for Order of Magnitude and Pre- Feasibility or Feasibility studies.

The use of microdiamond sampling for diamond content estimation involves diamond core drilling, which is also used for the development of deposit geology and geometry. Core is laid out in core boxes and subsamples are visually selected according to a sampling protocol to ensure correct sampling procedures and repeatability of the sampling process.

Microdiamond subsamples vary between 8kg and 20kg, but subsample size is at times determined by the nature of the occurrence. For instance, intersecting a thin dyke may not always yield the predetermined subsample size.

Initial sampling commences with little or no knowledge of the deposit and the aim of initial sampling is to establish whether the occurrence is diamondiferous. If it is, then the results of the initial sampling program can be used to design a sampling protocol for further sampling.

Reconnaissance sampling is the first sampling phase and is aimed at determining the extremities of the occurrence and a preliminary description of internal geology, such as the amount of overburden and an impression of the complexity of geology from drill core. This phase is also concerned with the occurrence of other bodies nearby which may contribute to an eventual mining operation.

This is followed by **exploration** sampling, aimed at diamond content by domain and estimates of average diamond value. The geological model is revised and improved with every additional hole drilled. An occurrence may be abandoned outright during the reconnaissance phase, but it is possible that a potentially marginal project may hinge on confirmation by further sampling even in the exploration phase. This phase may also take place at an operating mine where sampling is required to extend the resource to deeper levels that have not been sampled before.

Reconnaissance and Exploration sampling provide information to determine if there are reasonable prospects for eventual economic extraction (RPEEE), or to perform a preliminary economic assessment (PEA). These studies are eventually followed by more detailed **advanced sampling** programs. [45]

1.7 Application

Microdiamond sampling is currently applied in reconnaissance and exploration sampling at almost every new primary source of diamonds. The author was involved in applying and testing microdiamond methodology successfully at the following occurrences:

- Gacho Kue kimberlites in Canada.
- The Fort a la Corne kimberlites in Canada.
- Kimberlites in the Slave province in Canada
- Orapa, Letlhakane and Jwaneng mines in Botswana.
- Venetia mine in South Africa.
- Diamond content estimation at the Lomonosov and Grib kimberlites in Russia. [16]
- Estimation of Premier Mine C-Cut.
- Estimation of diamond content in Du Toits Pan mine, Kimberley
- Koffiefontein, South Africa.
- Marsfontein kimberlite and dykes, South Africa.
- Estimation of Finsch Mine Block 4 diamond content.
- Diamond size distribution modelling for AK6 (Karowe Mine) in Botswana.
- Development of resources in Lesotho. [39]
- Development of Tongo Dyke deposits in Sierra Leone.
- Assessment of diamond content in the Lace Mine, South Africa.
- Kimberlites in the DRC and Angola.
- Analysis of Snap Lake microdiamond sampling results.
- Exploration on Baffin Island in Canada and assessment of diamond potential for Chidliak pipe CH31 and others.
- Numerous other deposits in Canada, including Attawapiskat kimberlites.
- Initial evaluation of Victor Pipe in Canada.
- Assessment of kimberlites in South America.
- Lahtojoki kimberlite in Finland.

1.7.1 Further research

Several aspects of the application of microdiamonds in mineral resource estimation require further research.

- The assumption of a lognormal size distribution has yielded successful results, but other distributions are to be considered.
- Quantification of uncertainty associated with estimates.
- Application of microdiamond sampling for ore reserve control.

- Implementation of sample size reduction methodology and the role of microdiamonds in work relating to Sampling Theory by Pierre Gy.
- Practical aspects such as critical weight, average class weights, flexibility with respect to size class selections.
- Methodology associated with ‘Diamond within Kimberlite’ (DWIK) technology.
- Local estimation and simulation based on microdiamonds [37].
- Sampling strategies that target the +0.3mm microdiamond size fraction for kimberlites with low diamond concentration and coarse diamond size distribution.

PART I METHODOLOGY

2 Diamonds in Kimberlite

Résumé

Un gisement de diamants est souvent constitué de plusieurs types de kimberlites, émanant de différentes éruptions volcaniques survenues à des millions d'années d'intervalle. Chaque type de kimberlite a ses propres caractéristiques de pierres en matière de concentration, de taille et de valeur. L'évaluation du gisement commence par la mise au point d'un modèle géologique qui identifie les différentes kimberlites qui le constitue et en détermine les caractéristiques. L'échantillonnage utilisé pour cette phase de reconnaissance est lui-même fonction de ces caractéristiques.

Une caractéristique importante des gisements de diamants est la nature discrète de la minéralisation, et la granulométrie des pierres joue un rôle essentiel dans l'estimation de leur valeur moyenne. Cette distribution granulométrique s'étend sur une large gamme de valeurs, allant de quelques microns à quelques millimètres. De façon générale, les pierres commercialisables ne se trouvent pas en abondance dans le gisement. La découverte d'une pierre de grande taille est rare et constitue un évènement en soi. Les pierres les plus petites sont les plus fréquentes, et de ce fait jouent un rôle important dans le processus d'échantillonnage et d'estimation, même si elles n'ont aucune valeur économique.

Les ressources en diamants d'un gisement de kimberlite sont principalement spécifiées par deux facteurs, à savoir la concentration en pierres et leur granulométrie. La présent chapitre explique en détail la façon dont ces deux facteurs affectent les procédures d'échantillonnage et d'estimation, en accordant une importance toute particulière à l'acquisition des données de microdiamants et de leur utilisation. La description des opérations d'une procédure séquentielle type d'estimation conclut ce chapitre.

Overview

A kimberlite deposit often comprises more than one kimberlite family, each family composed of material from a different volcanic pulse occurring millions of years apart. Material from each pulse contains a diamond assortment that is unique with respect to the amount and value of diamonds contained, or may be barren. A deposit is examined by means of sampling in a way that is determined by the distribution and amount of diamonds present in the deposit. Evaluation begins with the

development of a geological model that defines the composition of the ore body in terms of the characteristics of the kimberlite material it contains.

The particulate nature of diamonds is characteristic of diamonds and the distribution of diamond size plays a vital role in estimating the amount and average value of diamonds. In the context of the research the most important characteristic of diamond mineralisation is that diamonds occur as unique assortment in a deposit, containing stones occurring in a continuous size distribution from micro sizes to large valuable stones. Diamonds of commercial size do not occur in abundance and large diamonds are so rare that its occurrence is often newsworthy. Small diamonds are most abundant and although worthless in terms of monetary value, are highly valuable for sampling and diamond content evaluation.

The amount of diamonds in a deposit is determined by two variable components, diamond concentration and diamond size. The characteristics of the assortment of diamonds contained in kimberlite are discussed with respect to sampling and estimation. The emphasis is on the collection and application of microdiamond information. For perspective on sampling and estimation procedures the chapter concludes with a typical evaluation sequence.

Microdiamond sampling initially leads to an estimate of the amount of diamonds in situ. Recoverable diamond content is derived by taking cognisance of losses due to the application of a bottom cut-off size during production.

2.1 Kimberlite Deposits

Diamonds occur in stable chemical form in the upper Mantle of the earth in a domain known as the Diamond Stability Field.

Kimberlite is generated at great depths in the earth and is emplaced at surface in pipes, dykes or sills. It is the most important primary source of diamonds and is the rock that is responsible for transporting diamonds from deep in the mantle to the surface. The name comes from Kimberley where the first major primary diamond discoveries were made in the late 19th century, at that time a small town in South Africa. Only a small minority of kimberlite bodies contain diamonds in sufficient quantities to be regarded as diamondiferous ore. [24]

The most acceptable hypothesis about the formation of diamond in kimberlite is xenogeneic. According to this hypothesis the formation of diamonds takes place within the peridotitic and eglogitic rocks which make up the lithospheric upper mantle of the earth. Diamonds in this rock are transported to the earth surface by complex processes involving volcanic activity, the nature of which in itself determines whether diamond is eventually present in the cooled rock. [25]

When the magma reaches surface it violently erupts, creating a crater which fills with the magma and other rock inclusions and cools down to form a diamond bearing 'pipe'. At least two varieties of diamond bearing kimberlite occur in Southern Africa, namely basaltic (group 1) and lamprophyric (group 2).

Group 1 kimberlites are Jwaneng, Orapa, Venetia and Premier Mines.

Group2 kimberlites are Finsch, Lace, Voorspoed, but occur mainly in the form of dykes. This kimberlite variety shows greater affinity with lamproites and is so distinct that it is known also as orangeites. [24]

Most of the known primary diamond-bearing deposits occur in the form of kimberlite pipes, with the exception of Argyle Mine in Australia which is a Lamproite pipe. A cluster of Lamproite bodies has also been discovered in India.

Other more abundant minerals that occur with diamonds in the mantle are included in the cooled rock and are known as indicator minerals. Most common are pyrope garnet, ilmenite, diopside and spinel. Their physical characteristics of shape, colour, hardness and density allow them to survive magmatic transportation along with diamonds. They can thus be distinguished as indicator minerals from similar minerals formed under different conditions [43]. Their presence in soil samples is used to detect kimberlites and is one of the methods used in diamond exploration.

The image in Figure 2-1 shows a cross section of a simplified kimberlite pipe with its three distinct zones identified - Crater, Diatreme and Root.

The infill above the Diatreme comprises a mixture of sand, kimberlite and other surrounding material forming a crater zone, often comprising more than one different litho-facies.

The diatreme is composed of Tufficitic Kimberlite Breccia and overlays the Root zone, which comprises Hypabyssal Kimberlite.

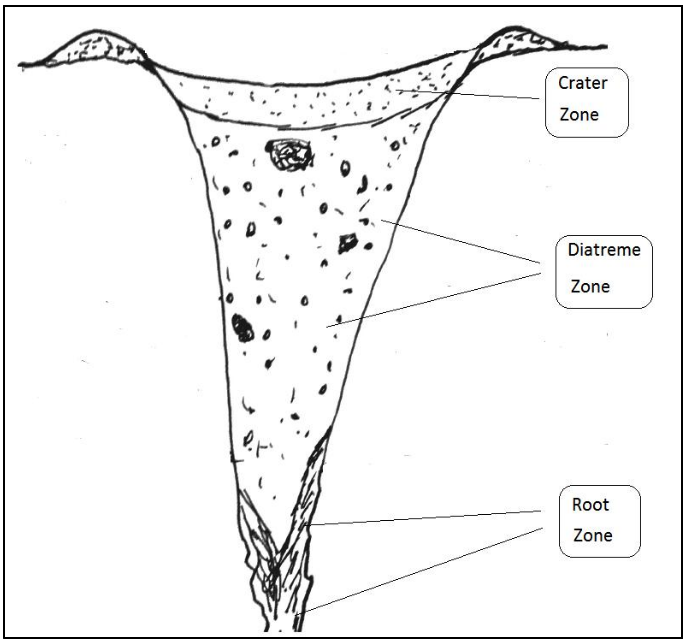

Figure 2-1 : Cross section of Kimberlite pipe

A kimberlite body may comprise material from different volcanic events, which may have occurred millions of years apart.

Apart from the initial deposition, later secondary influences on the deposit play a role in determining the nature and composition of the upper crater. Crater facies could comprise material from different events that took place locally and even from other pipes located nearby. In some cases the entire crater facies is removed through erosion, transporting the diamonds into rivers and eventually into the sea, forming secondary diamond deposits and leaving only the diatreme and root zones. In cases such as the Kimberley pipes even the diatreme has been eroded to expose the Root zone.

Kimberlite does not occur only in the form of kimberlite pipes. Magma often moves upwards reaching the surface through fractures in the crust that present easier passage for the boiling magma to form dykes and fissures. Examples of such occurrences are the Snap Lake dyke in Canada and the Motete dyke in Lesotho.

The presence of inclusions made up by other material collected during the transportation process results in every kimberlite having unique characteristics. Kimberlites normally occur in clusters, with each pipe in a cluster having its own unique characteristics.

If a pipe was formed by more than one volcanic event the kimberlite will comprise of more than one kimberlite type or family. Each kimberlite family will have unique diamond content characteristics. Other factors may contribute to the occurrence of different facies with unique characteristics.

For evaluation purposes it is important to examine the composition of a kimberlite pipe in order to identify all domains with similar characteristics. Any given domain will have unique diamond content and diamond value and may have different properties affecting the way material should be treated for diamond liberation. The existence of a common size distribution within a domain implies diamond content can be directly derived from diamond concentration within the domain [2] .

The phases of eruption forming the deposit create a geological footprint which has to be pieced together in the form of a geological model. It is difficult to create an acceptable geological model without some understanding of the process of deposition.

Diamond content and diamond value determine the economic potential for the deposit. Each diamond assortment has a specific size distribution and comprises different populations of diamonds, some more valuable than others. A deposit is therefore sampled from the outset to provide information on pipe geology and geometry, diamond content and diamond value.

Pipe geology maps the composition of the deposit by kimberlite family or domain and the amount and nature of material contained. Sampling is carried out to develop a geological model and to recover diamonds for the estimation of diamond content and value.

The accuracy of the geological model becomes critical if some domains in the pipe are financially marginal while others are highly economical for mining. Accurate assessment of the economic potential of a deposit is impossible without a reliable geological model. [23]

2.2 Diamonds in Situ

In a given volume of kimberlite the number of diamonds is less variable than their total weight. The homogeneity of the host rock is due to its chemical composition as well as the mechanics that took place during deposition. When added to other geological observations this confirms the understanding that the diamond had already crystallised before the emplacement of the kimberlite, which was accompanied by important mechanical mixing [12].

A two-stage formation process is suggested with respect to the genesis of a population of diamonds mixed from sources containing size distributions ranging from positively skew to symmetric. The first stage is a phase of germination during which the carbon molecules progressively occupy all the possible points of attachment in the enveloping rock. In this stage germination has precedence over growth, the mass of small particles is by far the most numerous and the distribution is positively skew. The second stage is a phase which sees growth taking precedence over germination. All the attachment points have been occupied, the crystals already in the enveloping rock have been swelling and the resulting size distribution could be less positively skew, more symmetric and perhaps even negatively skew. [12] However, the positively skew nature of diamond particles formed through growth and decay suggests that sub-populations of crystals with negatively skew size distribution would be very rare.

The processes of diamond growth and resorption are closely interwoven with the formation and the ultimate presence of diamond in kimberlite. Both processes affect diamond size, which eventually exhibits a positively skew distribution. In practice the lognormal distribution has been applied extensively in diamond size distribution modelling.

Other distributions describing diamond size are not ruled out, but the lognormal distribution has been successfully used in all the research leading up to this thesis. The reason for this is attributed to the collective characteristic of the diamond assortment contained in a kimberlite domain and gives weight to the assumption of one, single, diamond size distribution in each domain within a pipe [11].

The advantage of the positively skew nature of diamond size distributions is that kimberlite would normally contain a higher concentration small stones. If sampling is focused on small diamonds, it is possible to draw smaller samples and still obtain enough stones for estimation purposes.

Figure 2-2 : Diamond partly embedded in kimberlite (Rough Diamond Website)

The image in Figure 2-2 shows a rough diamond embedded in a piece of kimberlite. The hardness of this piece of rock seems evident. The rock most likely contains many small stones not visible on the photo, but when subjected to acid dissolution treatment they will appear. The large stone that is visible is rare and will be prominent in the diamond parcel recovered from the material containing this rock.

This is the nature of diamond size distributions and the presence of stones such as this one is what turns a deposit into a resource, while the small stones are most useful for determining diamond content associated with the kimberlite hosting this rock.

2.3 Microdiamonds

2.3.1 Definition

The definition of microdiamonds is entirely based on size and was initially accepted to be stones smaller than the commercial bottom cut-off screen sizes of 1mm.

The accepted definition is that a microdiamond is a stone that would pass through a 0.5mm square mesh screen. This implies that at least two of its major axes have to be smaller than 0.5mm. The important fact is that the definition is based on size alone and not on any other diamond characteristic or natural discontinuity in the size distribution of diamonds.

For all practical purposes there is no need to distinguish between micro and macrodiamonds.

Figure 2-3 shows images containing microdiamonds depicting size relative to a 10mm scale and in relation to an ordinary paper staple.

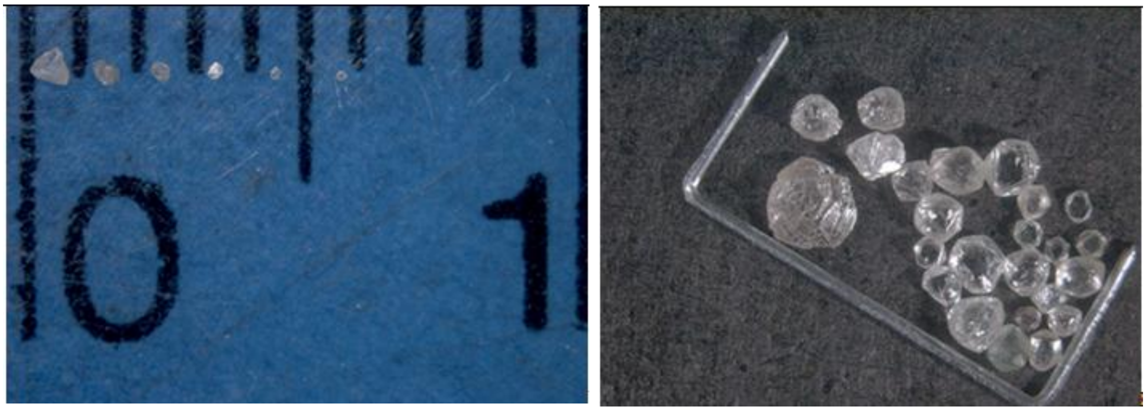

Figure 2-3 : Microdiamond photos by courtesy of Kimberley Microdiamond Laboratory

The bigger stone on the left on the ruler is not a microdiamond as per definition, as it seems unlikely to pass through 0.5mm square mesh, but it would nevertheless form part of the analysis. Microdiamond sampling does not restrict recovery to microdiamonds – it extends recovery down to the microdiamond sizes below 0.5mm with popular bottom cut-off in the industry set at 0.075mm without any restriction on maximum size.

2.3.2 The Beginning

The existence of microdiamonds was first mentioned in the literature in 1892 by Couttolenc, who treated -2mm tailings material from the De Beers Mine in Kimberley [9]. This was done only to examine kimberlite for the existence of microdiamonds and was not an attempt to link microdiamonds with the macrodiamond content of the deposit.

Others followed, but the idea of using microdiamonds for diamond content estimation was first mentioned in the literature by Williams 40 years later, based on the abundance of small stones [61],

"In the treatment of kimberlite many very small diamonds are recovered. The small diamonds sometimes average 80 to 100 to the carat.", and "From careful tests it has been proved that these small diamonds bear some relation to the number of larger diamonds found in any particular area of the mine", as quoted by Davey in his thesis [11].

As general manager of De Beers Consolidated Mines, Williams recognised the potential to use microdiamonds to estimate macrodiamond grade, but clearly did not apply his theory, as De Beers only started using this technology in the late 1960's.

Deakin and Boxer made use of microdiamonds for macrodiamond grade estimation in 1986 at the Argyle Mine in Australia [2]. They proposed the representation of diamond content in the form of the LC-curve as shown in Figure 1-3.

Further out in the field, application of the methodology was hampered by the belief that microdiamond sampling was subject to serious limitations with respect to inference on diamond content. This lack of confidence in the methodology unfortunately resulted in a lack of focus on basic sampling principles, which most of the initial material collected often did not meet.

Since its inception as indication of diamond content, results from all anomalies have consistently suggested a continuous diamond size distribution.

Oosterveld at De Beers was responsible for most of the initial development and application of microdiamonds in the Company and laboriously initiated sampling from all the known kimberlites owned or controlled by De Beers. He also obtained results from new discoveries, notably pipes in

Canada when those were at their early stages of sampling and became a world expert in this field. Without any doubt he also experienced the scepticism of unbelieving geologists, also from within the ranks of his colleagues.

The early days of microdiamond analysis did not allow much time to improve sampling procedures or to even consider the possibility of microdiamond sample stone counts being regionalised in space. To make things worse, its application was dampened also by the consequences of unrealistic expectations (Personal experience). Disillusion following uninformed expectations of high grade associated with high microdiamond frequency fanned the flame of scepticism. (Similar incidences have been observed even as late as 2013.) However, results continued to provide sufficient inspiration to ensure the application and further development of the methodology along with maintenance of treatment facilities.

2.3.3 Application

Discovery of an 'anomaly' could be based on ground work involving Indicator minerals and confirmed by magnetic survey, or could be due to detection of the magnetic anomaly without any ground work. In either case material has to be collected to establish whether the anomaly is kimberlitic and diamondiferous. Geochemistry is applied to determine if the material is kimberlitic, but ultimately diamonds must be recovered to prove the presence of diamonds.

The use of microdiamonds as an indication of the presence of commercial diamonds is introduced for application during the early sampling stages. Small samples are sent off for laboratory testing before heavy equipment is introduced to perform large diameter drilling (ldd) for diamond recovery.

Research leading to this thesis has elevated microdiamond sampling from a tool regarded as merely providing an indication of diamond potential to a potent sampling methodology. Proper sampling procedures were introduced and the important issues of diamond concentration and size are addressed by application of the methodology.

The approach of using microdiamond sampling for diamond content estimation synchronizes with the collection of information on pipe geology, pipe geometry and diamond liberation and allows less troublesome and more comprehensive evaluation from greater depths in a deposit at lower cost [18].

Under normal conditions microdiamond samples are treated in units (subsamples or aliquots) of approximately 20kg or 8kg, depending on the treatment facility used. If an intersection does not yield the specified subsample weight, the smaller weight is treated anyway. This often happens when drilling through a dyke to collect sampling material from depth. Under such conditions even small amounts of material is useful as it may be the only information available for diamond content estimation. The size of the sample will however determine the type and quality of estimate and the associated level of confidence.

Microdiamond sampling is focussed on the recovery of microdiamonds, but diamond recovery and interpretation of sampling information are not limited to microdiamonds only. The occurrence of a large stone in a microdiamond sample can create problems with interpretation of diamond content and sometimes have to be regarded as an outlier and ignored in order to avoid creating over-optimistic expectations. However, it always provides confidence that larger stones are contained in the source.

Individual bulk samples for macrodiamond recovery are usually larger than 1000kg and most of the stones in the sample material are screened out along with undersize material (< 1.5mm for instance). The net effect is that much information is screened out as undersize, while a small sample with small bottom screen aperture might provide even more representative information about diamond content.

Unless the nature of diamonds in kimberlite and the consequences of screening are understood, it will be difficult to accept that samples of 20kg may provide the same level of information as a sample of 1000kg or more.

2.3.4 Benefits

Kimberlites occur in clusters and new discoveries are often subject to swift examination in order to identify the most economic bodies. For this reason it is essential to be able to prioritize an ore body on the basis of a small amount of sampling data collected with minimum cost and effort in the shortest time period. This is possible by means of sampling for microdiamonds, which provides the essential information. However, the size of sample required in the case of large ore bodies inevitably leads to a phased approach.

As a rule, diamond content is the first variable of interest to be measured. If diamond content does not appear to be interesting, then there is no further interest in the deposit.

The use of microdiamonds to determine diamond content in kimberlite has the following advantages:

- It allows the use of small samples for diamond content estimation and can be collected from drill core. Core drilling is quicker and cheaper and is done with more mobile equipment with easier access to difficult terrain.
- Core drill holes can be angled and can be directed to particular zones in a kimberlite if required.
- Quicker drilling time is less likely to cause disruption in an open pit environment during mining activities.
- Sample collection takes place from visible core.
- Samples are small and easy to handle and store. It is therefore easy to keep core for audit purposes. Samples can be treated and results interpreted during progression of the sampling program, allowing changes to the sampling protocol if suggested by interim results.
- Sample weight is determined directly and accurately, no material is lost in undersize. There is no need to calliper a drill hole in order to determine sample volumes to estimate sample weights.
- The relative density of sample core can be determined when sample selection takes place and enables expression of grade also in terms of diamond content per resource volume if required.
- Kimberlite dilution (contamination by non-kimberlitic inclusions) can be assessed before sample core is bagged and dispatched for treatment.
- The methodology allows diamond content assessment for recovery at any selected bottom screen size.
- There is no pressure to sell sampled microdiamonds as these stones have no commercial value.
- There is minimal security risk associated with treatment and recovery, which is a costly component when commercial size diamonds are recovered.

Diamond content evaluation and sampling methodology based on microdiamonds are applicable from the time when a deposit has been confirmed as being kimberlitic, through to the final evaluation phases for mining feasibility.

2.4 Sample stones and sample carats

Before considering representations for the distribution of diamond size it is necessary to distinguish whether the weight or number of diamonds per size class should be used. [55]

Figure 2-4 compares the distribution of stone numbers and stone weights in the same diamond parcel and illustrates the advantage of sampling from the abundance of small diamonds. The loss of information when using a bottom screen size of 1mm (~0.01057 carat or +1 diamond sieve) is emphasized. The example reflects recovery at 0.075mm screen size (~0.0000018 carat) and depicts the distribution of the number of stones per size class and the corresponding carat weight per size class, with size increasing from left to right on the X-axis.

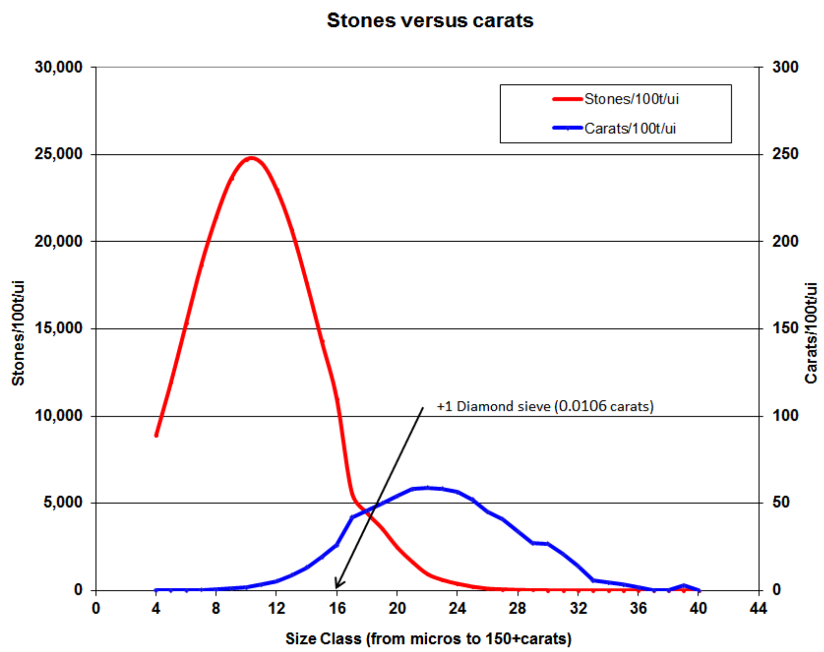

Figure 2-4: Graph depicts carat weight and stone count by size class, showing the abundance of stones below commercial bottom cut-off size.

The arrow indicates truncation at approximately 1mm. If sampling is focussed on the recovery of diamonds below 1mm more stones are recovered, which allows the use of smaller samples.

The graph shows more carat weight to the right of the 1mm line because the stones are larger, therefore the classes contain more carats. But it does not imply that more information is available with regards to diamond content. Furthermore, carat weight as measure of sample recovery includes diamond size as additional source of variation. This is further discussed in the chapter on diamond content modelling.

2.5 Diamond Size

Diamond content is the first variable to be estimated when evaluating any diamond deposit. Certain properties of the distribution of diamond size, as shown in the following graphs, must be known in order to understand the reason for some aspects of the evaluation process.

A histogram representation of the size breakdown of a typical +0.075mm diamond parcel is shown in Figure 2-5.

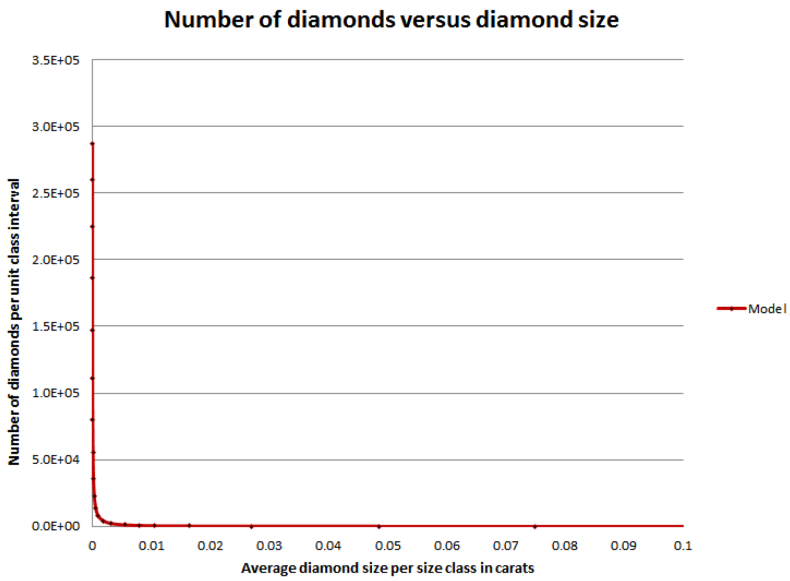

Figure 2-5: Diamond size class frequency versus average size

The X-axis reflects diamond size in carats and the Y-axis reflects the actual number of stones per size class normalised with respect to the width of the size class. The Frequency of small diamonds is so high that it appears as if there are no large diamonds in the source. The graph is limited to a maximum stone size of 0.1 carat.

Log transformation of diamond size improves the representation and the resulting graph is as shown in Figure 2-6.

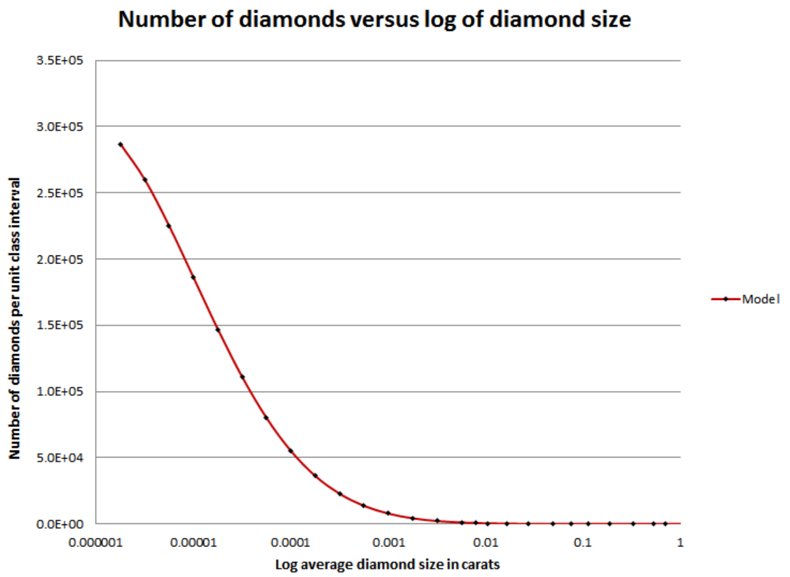

Figure 2-6: Diamond size class frequency versus log diamond size

This is a plot of the same diamond parcel shown in Figure 2-5 except that diamond size is depicted in terms of the logarithmic carat value.

The previous graphs (Figure 2-5 and Figure 2-6) represent the distribution of diamond size, depicting diamond frequency in size classes relative to one another, without reference to the amount of material in the source. When the weight of material associated with the diamond parcel is known, the graph is adjusted to represent diamond concentration. Diamond occurrence is now expressed in terms of stones per unit class interval per tonne (or per 100 tonnes) and plotted against diamond size on a log scale.

This transformation results in diamond concentration being represented as **a log-concentration curve (LC-curve)** in the form of a 2nd degree polynomial as shown in Figure 2-7.

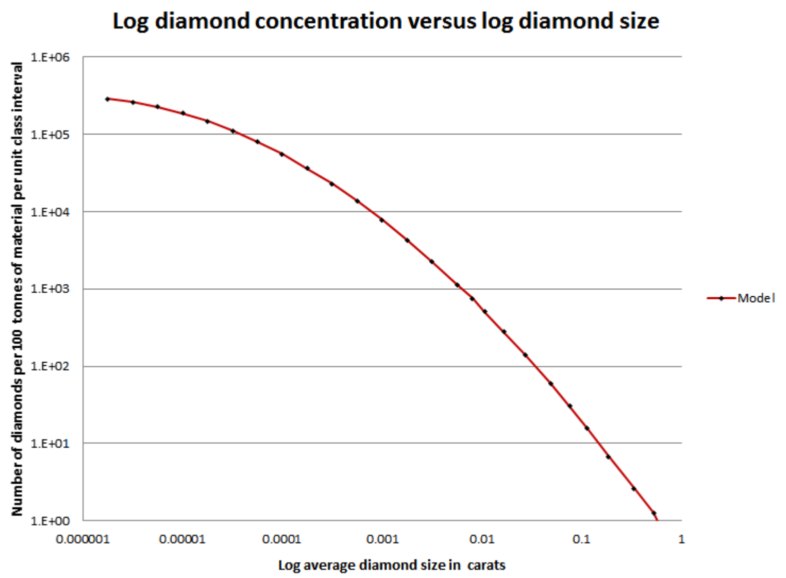

Figure 2-7: Log diamond concentration versus log diamond size (LC-curve)

The graph in Figure 2-7 represents the same diamond parcel as shown in the previous two graphs (Figure 2-5 and Figure 2-6), but it contains more than a breakdown of diamond frequency in size classes. By expressing diamond frequency relative to the amount of source material the graph depicts the breakdown of diamond concentration with size, which leaves a short step towards diamond content in the source.

Class grade (carats/tonne) is calculated from class concentration and average diamond size. Accumulation of class grades above the truncation level amounts to average deposit grade in carats per tonne. Deposit diamond content in total carat weight (above truncation level) is calculated given the total tonnage estimated for the deposit and applying average grade in carats per tonne.

The LC-curve is easy to model and makes it possible to calculate diamond content above any given bottom cut-off and within any size class.

The graph shows that most of the diamonds in the parcel lies below 0.01057 carats, which is the lower class limit for +1 diamond sieve[10]. This representation is particularly useful when microdiamond results are available and presented in the form of size class frequencies. Deakin and Boxer reported their use of the representation of diamond content in the form shown in Figure 2-7 for grade estimation at the Argyle Mine in Australia [2].

This representation of diamond content has been used by the De Beers family of companies since the 1970's as well as other companies in the Industry. It is useful to indicate grade potential during early exploration phases when only microdiamonds might be available as well as during final estimation of diamond content based on results from advanced sampling.

Diamond grade in a deposit is expressed in terms of carat weight per unit weight of in situ material and is completely specified only if it is accompanied by a size breakdown of diamonds. This is normally given in percentage carats per sieve class for a fully representative diamond parcel.

2.5.1 Diamond size frequency and log Probability

Working in a production environment means that diamond parcels normally comprise thousands of stones. To eliminate laborious counting, diamond parcels are sieved into size classes.

Research for this thesis is based on stone numbers by size class and the convention is followed even for small parcels of diamonds. If stones are not counted by size class then class diamond weight is converted to class stones by means of the known average diamond size per size class.

Diamond sieving is an important aspect in the Industry and several combinations of sieving are in use. The two most frequently used systems in the research are the Diamond Trading Company (DTC) and Antwerp sieve systems.

Modelling is capable of taking cognisance of every combination of size classes. Table 2-1 is an example of a diamond parcel broken down in size classes.

[10] DTC sieve with round aperture 1.092mm

Table 2-1: Microdiamond parcel broken down into size classes. Parcel contains micro and macrodiamonds from microdiamond sampling.

	Size class number (1)	Diamond Sieve (2)	Lower Critical size Carats (3)	Stone frequency (4)	Percentage stones more than lower class limit $100(1-F(x))$ (5)	Inverse Gaussian value $G^{-1}(1-F(x))$ (6)
Macro-diamonds	32	15+	14.8		0	
	31	+23	8.036		0	
	30	+21	3.691		0	
	29	+19	1.918		0	
	28	+17	1.423		0	
	27	+15	1.195		0	
	26	+13	0.703	0	0.0000	
	25	+12	0.523	0	0.0000	
	24	+11	0.317	1	0.0233	-3.4998
	23	+9	0.179	2	0.0698	-3.1953
	22	+7	0.117	0	0.0698	-3.1953
	21	+6	0.0792	1	0.0931	-3.1114
	20	+5	0.0485	0	0.0931	-3.1114
	19	+3	0.0256	8	0.2793	-2.7711
	18	+2	0.0186	6	0.4190	-2.6364
	17	+1	0.01057	17	0.8147	-2.4023
Micro-diamonds	16	c16	0.01000	2	0.8613	-2.3819
	15	c15	0.00562	46	1.9320	-2.0680
	14	c14	0.00316	33	2.7002	-1.9268
	13	c13	0.00178	76	4.4693	-1.6986
	12	c12	0.001000	95	6.6806	-1.5000
	11	c11	0.000562	116	9.3808	-1.3177
	10	c10	0.000316	173	13.4078	-1.1073
	9	c09	0.000178	226	18.6685	-0.8902
	8	c08	0.000100	257	24.6508	-0.6855
	7	c07	0.000056	309	31.8436	-0.4721
	6	c06	0.0000316	441	42.1089	-0.1991
	5	c05	0.0000178	501	53.7709	0.0947
	4	c04	0.0000100	649	68.8780	0.4924
	3	c03	0.0000056	587	82.5419	0.9362
	2	c02	0.0000032	405	91.9693	1.4030
	1	c01	0.0000018	345	100.0000	
				4,296		

Class frequencies are accompanied by their percentage more than frequencies in the table and the inverse Gaussian value associated with the corresponding probability. (This is the value of a standardised Gaussian variable associated with the corresponding cumulative probability.) Macrodiamond size classes are given in terms of DTC sieves (+1 to 15+) and microdiamond size classes are given in terms of quarter log intervals (C1 to C16). In the case of this example all the stones were allocated to size classes as their individual weights were known. Most producers physically sieve their microdiamonds into standard mm size classes.

The distribution of diamond size can be depicted in the form of a frequency histogram that represents the statistical distribution of stone size.

Class frequencies are normalised to unit class interval length to eliminate the effect of unequal class intervals.

Alternatively, for modelling purposes the size distribution is represented by the cumulative ‘more than’ distribution function, representing the probability of any randomly drawn stone from the stone population to weigh more than the given weight on the X-Axis and plotted on a probability grid as a **log probability curve[11] or LP-curve**.

An LP plot for the sieving in Table 2-1 is shown in Figure 2-8.

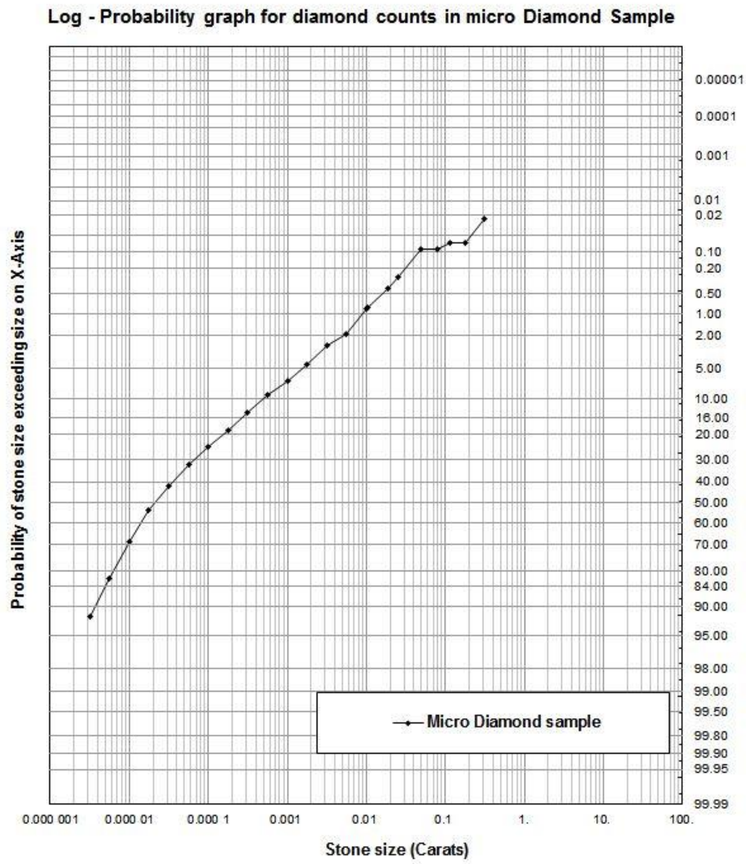

Figure 2-8: Log Probability plot for microdiamond parcel in Table 2-1

The lower critical size shown in the table is the lower class limit in carats and is source specific.

The points in the graph are formed by plotting the inverse Gaussian value (column 6) in the table against its corresponding lower class limit (column 3) and annotate the Y-Axis by the associated probability (column 5) as shown. The Y-axis is reversed in accordance with practice that stretches over decades and which is maintained in the thesis for practical purposes.

The microdiamond sample in Table 2-1 is represented by the black line. The sample contains more than 4,000 stones, which is large compared with subsamples that may contain less than 100 stones.

More than one sample may be plotted on the same graph, including macrodiamond samples from bulk sampling. This is adequately illustrated in the text, but an example of multiple microdiamond subsamples is given in Figure 2-9. The graph shows size plots for 13 microdiamond subsamples with a plot of the combined sample parcel for the domain sampled. Recovery took place above 0.075mm square mesh, or approximately 0.0000018 carats.

[11] This curve is also known as a size frequency curve, or size frequency distribution (SFD). The latter terminology is not used in the thesis.

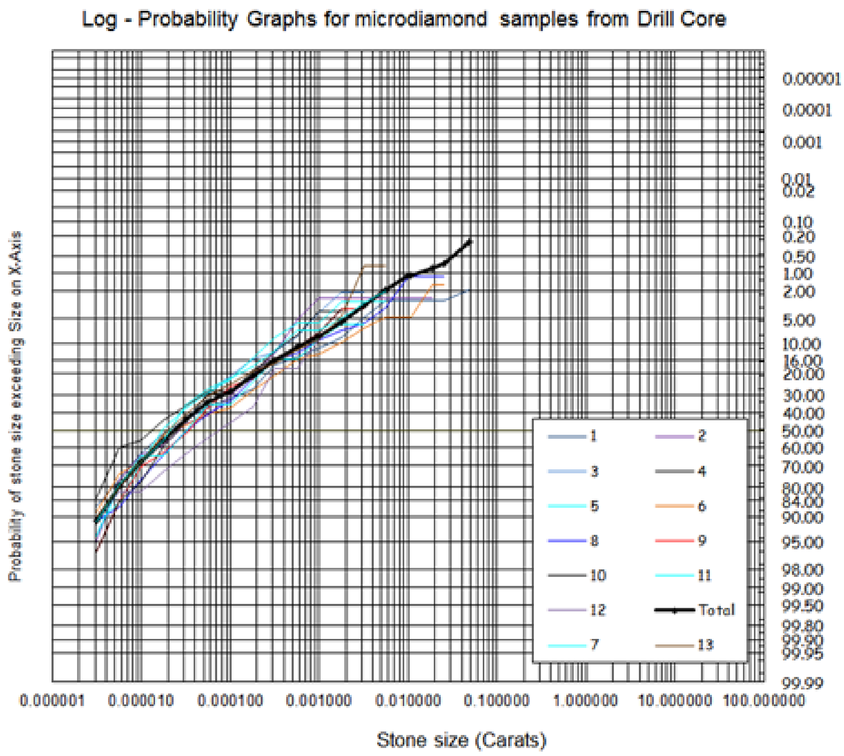

Figure 2-9 : Log Probability graphs for microdiamond subsamples

In addition, the graphs in Figure 2-9 illustrate the tendency of each subsample from a domain to reflect the domain diamond size distribution. The combined sample represented by the solid black line covers the entire size range sampled, shows less fluctuation between size classes and approaches the size distribution for the domain. This is the extent to which the subsamples collectively represent the domain.

The following points are notable from the size representations in Figure 2-9:

1. The regularity of the subsample size distributions shows that every subsample contains an 'image' of the population in the domain; no subsample contains only small stones or only large stones.
2. If the number of subsamples is increased the global curve becomes more regular, with less fluctuation from size class to size class;
3. There is no indication of any discontinuity between micro and macro diamonds in any of the subsample graphs;
4. The spread of the curves suggests the potential for substantial uncertainty when relying on a **single** small subsample.
5. The combined sample stone size distribution asymptotically approaches the population size distribution as the number of subsamples increases.

The total sample must be sufficiently large to recover enough stones to facilitate a stable estimate for the size distribution. The use of small bottom screen size combined with appropriate size, number and location of subsamples ensures representative sampling.

The efficiency of diamond size modelling depends on the number of diamonds considered, whereas the quality of an estimate for diamond concentration depends on the number of subsamples available from the source.

2.6 Diamond Liberation and Lockup

The particulate nature of diamonds requires special treatment and recovery procedures to prevent diamond breakage. A theoretical approach is given in [36].

Commercial diamond liberation takes place by means of staged crushing, beginning with a large crusher aperture to avoid crushing the larger stones. Primary crushing is normally done to produce an under-size product of 150mm, followed by secondary and tertiary crushing to around 30mm and 10mm. These apertures vary in accordance with the in situ diamond size distribution. Small and large diamonds are affected by the selection of top and bottom size thresholds during diamond liberation. Large diamonds in particular may be broken during the crushing process when particle dimensions exceed the limits imposed by crusher apertures.

Commercial diamond recovery takes place by means of dense (or heavy) medium separation (DMS or HMS), which removes less dense tailings particles from the treatment cycle under the premise that the higher density diamonds would be more likely to occur in more dense ore particles. This method of diamond separation is based on the relative density of the diamond, which is $3.51 \mathrm{gm/cc}$. Diamonds with inclusions have lower density. [50]

The benefit of recovering smaller commercial diamonds measured against the cost of treating smaller particles, determines the bottom screen aperture used in the recovery process. Undersize particles are discarded to slimes, since the value of small diamonds may not justify the cost of their recovery. Discarding slimes reduces the amount of material in the treatment cycle substantially and improves recovery of larger stones. Therefore, small commercial stones are either screened out as undersize or locked in tailings particles and discarded.

This type of treatment process is practical for diamonds larger than 1mm. If diamonds smaller than 1mm are to be recovered, a different recovery methodology is required.

Diamond lockup is eliminated with treatment procedures by which the host rock is dissolved, leaving diamonds and some heavy mineral particles as residue. Acid dissolution and caustic fusion procedures are used to recover microdiamonds and lead to total diamond recovery above microdiamond cut-off levels.

Application of a bottom cut-off removes stones with maximum dimension less than a given threshold, but stone shape does not allow a clean cut-off in stone weight – some heavier stones may form part of undersize, while some lighter stones may remain on top of the screen. The smaller size classes of the screened product therefore tend to contain only partial recovery of in situ diamonds.

This implies that the in situ diamond size distribution is not accurately reflected by the recovered diamond parcel, be it from microdiamond- or macrodiamond sampling and could affect the linearity of the associated LP-curves. Screening losses cannot be eliminated, except by lowering the bottom cut-off size, in which case the losses will only occur in size classes lower down. The use of microdiamonds effectively provides the means to obtain total diamond recovery estimates in the lower commercial size classes.

Bottom cut-off losses must be quantified in order to establish an economically optimal cut-off size for diamond recovery. This is achieved by estimating the associated screening and lockup factors which form an essential part of diamond content estimation.

2.6.1 Maximum locked diamond

The estimation procedure for diamond lockup is applicable to recovery of commercial size diamonds by means of Dense Medium Separation. This process is preferred above other densimetric processes as the quality of separation in a Dense Medium cyclone is far more precise. [40]

Diamond bearing particles are entered into a dense ferrosilicon medium to extract particles that are more likely to contain diamonds from non-diamond bearing particles. More than one stage of particle crushing takes place to prevent damage to larger diamonds and to liberate smaller diamonds that may be contained in larger kimberlite particles.

The separation process is based on the Archimedes principle, relying on the density of diamond to contribute to the weight of a kimberlite particle. If the weight of a particle of size $\mathrm{V_p}$, including a diamond of size $\mathrm{V_d}$, is less than or equal to the weight of the displaced dense medium at (cut-point) density $\mathrm{D_m}$, then the particle will float and be separated as tailings material.

The dense medium has density higher than the density of the host kimberlite and will float a kimberlite particle that contains no diamonds or diamonds that are too small to affect the combined particle-diamond density.

The process is known as DMS weight equivalence and is illustrated in Figure 2-10.

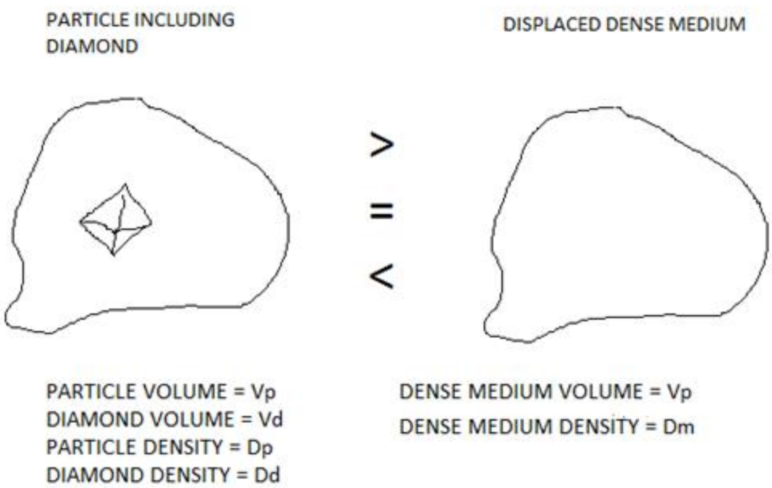

Figure 2-10: DMS Weight Equivalence

Unless the size of the particle is reduced to change its weight to volume ratio and entered back into the DMS circuit, the enclosed diamond will not be recovered. If the enclosed diamond is too small it may not be liberated and remain locked, or even be liberated and separated as undersize anyway.

If the weight of the particle is more than the displaced dense medium the particle will sink and form part of the concentrate that will be scrutinised for diamonds. This principle forms the basis for Dense Medium Separation which is a metallurgical process developed specifically for heavy mineral separation.

The maximum lockable diamond size $\mathrm{V_d}$ in a particle of size $\mathrm{V_p}$ and host rock density $\mathrm{D_p}$ in a dense medium with relative density $\mathrm{D_m}$ is derived from the DMS weight equivalence by considering the weight of particle including diamond with respect to the weight of displaced medium, as follows:

Mass of diamond + mass of particle is:

(i) less than mass of displaced medium

$$\mathbf{V_d} \times \mathbf{D_d} + (\mathbf{V_p} - \mathbf{V_d}) \times \mathbf{D_p} \leq \mathbf{V_p} \times \mathbf{D_m} \quad ==>$$

Particle with diamond floats and reports to tailings for re-crush or tailings dump

(ii) More than mass of displaced medium

$$\mathbf{V_d} \times \mathbf{D_d} + (\mathbf{V_p} - \mathbf{V_d}) \times \mathbf{D_p} > \mathbf{V_p} \times \mathbf{D_m} \quad ==>$$

Particle with diamond sinks and reports to concentrate for diamond recovery

Therefore, the maximum 'lockable' diamond in particle V_p at dense medium density (or cut-point) equal to D_m is given by V_d in the following equation: [12]

$$\boldsymbol{V_d} = \mathbf{V_p} \times \frac{(\boldsymbol{D_m} - \boldsymbol{D_p})}{(\boldsymbol{D_d} - \boldsymbol{D_p})}$$

If the particle contains a diamond larger than V_d , the particle will sink. The diamond may already be partially or fully liberated.

Experience with microdiamonds indicates that an average of 30 stones per 8kg sample, or 4 stones per kg, is not unusual for a viable deposit. Intuitively this supports the idea of no diamond, or on average not more than one diamond per kimberlite particle. This idea is also supported by the image shown later in Figure 3-1. Nevertheless, if a particle contains more than one diamond, then the theory holds for the combined size of the included diamonds.

The maximum lockable diamond size is therefore related to the size of the particle containing the diamond, the density of the enclosing material and the diamond density, which may all vary from particle to particle, and the dense medium density, which is externally controlled.

Distributions for these entities are obtained by means of sampling and with Monte Carlo simulation an estimate of potential diamond lockup can be calculated.

Given the appropriate information from the treatment circuit it is possible to make an assessment of anticipated diamond lockup. Information required for this purpose entails a breakdown of sample particle size distribution, the percentage material lost to slimes and grits, the proportion non-kimberlitic material per particle size class, kimberlite particle density and dense medium density.

Equally important is the assessment of losses due to screening, but this would be more difficult to do theoretically. A thorough knowledge of the diamond shape distribution is required for this purpose and estimates of all losses are made on the basis of a comparison of total diamond content and recovered diamond content from which screening losses could be derived. Losses are expressed as a factor by size class and are referred to as **bottom cut-off alignment factors**.

[12] Ferreira J.J., Tailings granulometry and diamond liberation, De Beers Metcon , 1999 , based on work done by Kleingeld et al on the investigation of diamonds potentially locked in clay at De Beers Marine, circa 1979

Reliable alignment factors are required to obtain estimates for grade and revenue in a production environment for economic studies.

It is important to note that the loss of small stones at the bottom end of the diamond size spectrum means that the sample size distribution is not a true reflection of the population size distribution. This must be taken into account in any type of analysis that is aimed at modelling the in situ diamond population size distribution.

The explanation of issues surrounding diamond liberation and diamond lockup seem superfluous in view of the fact that microdiamond sampling actually provides in situ diamond content information. Recovery efficiency of a sampling program can be quantified only if total diamond recovery per size class is known.

2.7 Diamond Value

Microdiamond sampling is not aimed at determining diamond value.

Diamond value becomes more relevant only at the stage when sampling has established that the deposit contains a potentially economic quantity of commercially [13]sized diamonds. During the reconnaissance and early exploration stages of sampling the main concern is to assess diamond content.

The size of diamond parcel that is required from the deposit to estimate average diamond value varies according to the nature of the diamond assortment. A general rule for the amount of carats required for resource classification is set in the Industry[14]. However, in practice this amount depends mainly on two factors, the nature of the diamond assortment and the accuracy required for the estimate. For instance, if the deposit seems marginally economic, then a higher degree of accuracy and therefore a larger diamond parcel is required.

The size of the parcel must allow calculation of average diamond value for size classes across the size range in order to obtain a relationship in the form of a revenue curve depicting average diamond value ($/ct) by diamond sieve class. (LV-curve for log-value versus log-size)

To value a diamond parcel, random subsets of diamonds from each size class are valued until a stable class average is obtained. In size classes with fewer stones all the stones are valued and the average calculated. Average Dollar/ct value for the class is applied to class carats to obtain total class value. The sum of class Dollars and carats yield average Dollar/ct value for the diamond parcel. If the diamond parcel does not fully represent the size distribution for the deposit the parcel value will not reflect the average value of the deposit.

Sampling rarely yields a fully representative diamond parcel with average diamond value for all size classes. The sample revenue curve is therefore almost always derived by means of a modelling procedure. In size classes where few or no stones occur an average is modelled by comparing the observed parcel averages with other known revenue models and with the average value of neighbouring size classes in the parcel. For this purpose average class values are plotted against diamond size to derive a LV-curve over the full size range.

Comparison with revenue models from known producers that are based on fully representative diamond parcels are used in collaboration with observed sample class averages. If this does not lead to an acceptable model for the LV-curve, then a larger sample is required before a firm revenue estimate is given.

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[13] Diamonds in excess of the +1diamond sieve

[14] Reliably based on at least 2000 carats according to CIM Standards on Mineral Resource and Reserves

Cut, Colour, Clarity and Carats are the four factors determining the value of an individual diamond and every diamond in an assortment is unique with respect to the four properties.

The overall value of a diamond parcel is directly related to the LV-curve and the coarseness of the stones in the assortment. A greater proportion of larger, higher valued diamonds will yield higher Dollar/ct average value and vice versa.

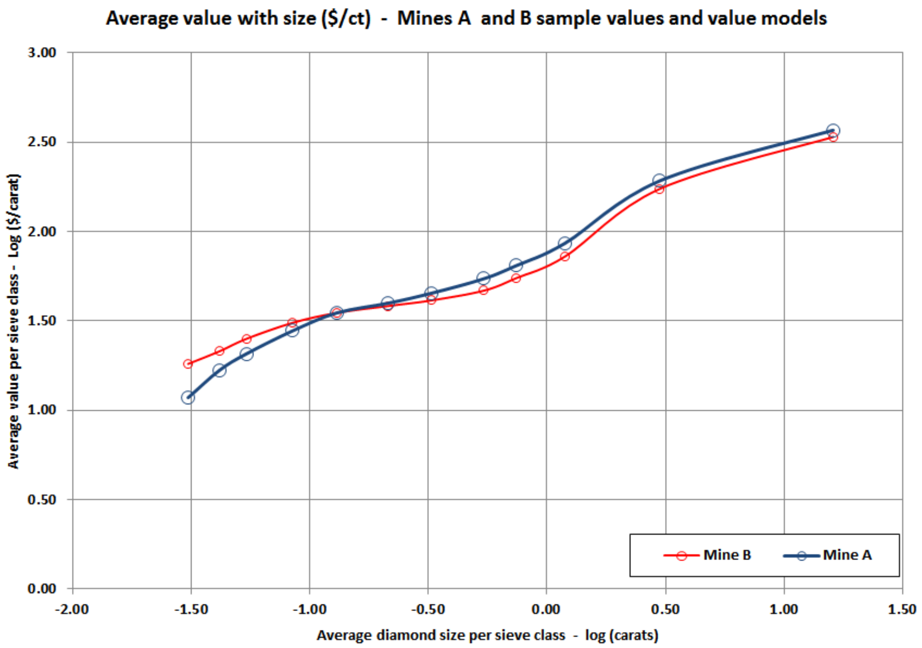

Figure 2-11: LV-curves for diamond parcels from two sources, indicating increase in average value with size and the difference between the two sources with respect to average diamond value.

The research is focused on the role of microdiamonds in providing a reliable diamond size distribution model and not necessarily on providing methodology for diamond value estimation. The purpose of the illustration is to show that the diamond size distribution is a main component determining average diamond value. As for diamond size, average diamond value is also to be determined for the in situ and eventually the recovered diamond assortment and not for the parcel recovered from sampling.

The benefit of using microdiamonds for diamond content modelling is that it leads to a size distribution model early in the sampling campaign. When the need arises to estimate diamond value, the opportunity is seized to confirm the diamond size distribution model which, at that stage, is based only or mainly on microdiamonds. With a confirmed size distribution model a much smaller diamond parcel is needed to obtain a reliable diamond revenue model.

Examples are presented in case studies. (Section 6.1.5.1)

2.8 Kimberlite Evaluation

The high cost of drilling and sample treatment demand a staged approach for kimberlite resource evaluation. Therefore sampling inevitably takes place in phases. [45]

A brief outline of deposit evaluation is given in order to provide proper perspective of the needs of sampling and estimation for diamond content in kimberlites.

Evaluation is aimed at assessing economic viability, which requires a resource model in terms of recoverable diamond content and diamond value, mining and treatment costs, mining and treatment detail, geo-technical and environmental issues and more. Only variables pertaining to diamond content or value are addressed in the thesis.

The main purpose of sampling is to collect information to estimate two basic resource entities, total tonnes of material to be mined and the total dollar value of diamonds contained in this material. These entities are calculated from variables that are measured directly by means of sampling.

From the outset the idea is to identify all geological domains in the deposit. Each domain is individually evaluated for compilation of the overall deposit value. Some domains could be diamondiferous but uneconomical when considered in isolation, but economically viable when considered with respect to neighbouring domains. A deposit may become economically viable on the basis of the value of only one of its domains or it may remain non-viable simply because of the problematic location of higher valued domains.

The importance of a resource variable varies during sampling phases. For instance, diamond value is an important variable, but in the initial sampling stage it is more important to assess diamond content. Once these entities are reasonably established, information on diamond value becomes more pertinent.

Diamonds, unlike most other mined minerals, have a particulate nature and as such should be kept intact during sampling and mining. The particulate nature of diamonds contributes to some unique features with respect to associated sampling and evaluation procedures.

2.8.1 Evaluation Purpose

When a kimberlite pipe is discovered, the immediate question is whether it is economically viable and what the value might be.

If it is viable it should be mined as soon as possible. If not, then the next prospect should be assessed as soon as possible. For the small venture operators it is important to establish good value fast and reliably in order to sell the deposit at the highest valuation. The only way to establish either option is by means of sampling. As first step of the evaluation process it can end quickly or can keep going for a while before it finally ends or continues until a mine is established.

2.8.2 Evaluation Sequence

At discovery an anomaly must be confirmed as kimberlitic and diamondiferous. Limited drilling is required to obtain core for geochemistry, diamond content analysis and an assessment of deposit geology.

Barren core poses the question of whether the core represents the kimberlite properly, but a minimum amount of drilling should be done from the outset.

Positive results will provide some indication of diamond size and concentration. Stone size frequency and sample stone concentrations are recorded for each sample taken and stored in a sampling data base. The lithology of each sample is recorded and geological logs of all drill cores are used to build a geological model for the deposit.

Drilling is directed at developing pipe geometry and geology. Data with respect to each identified litho-facies is recorded and analysed separately. The aim is to create a model for the pipe in 3D by identifying domains that are geologically similar and to obtain estimates for tonnage and diamond content by domain.

If diamond content appears to be at a possibly economic level, sampling is directed at obtaining macrodiamonds for valuation. This is achieved by means of mini bulk sampling or bulk sampling that takes place in the form of large diameter drilling or by excavating larger bulk material from trenches, pits, shafts or tunnels.

The availability of macrodiamonds immediately serves as confirmation of the size distribution as derived from microdiamonds and elevates the size distribution model to a higher degree of confidence.

Treatment of bulk ore allows studies to determine the type of treatment that will be suitable for mining.

More core drilling is done to improve the geological model and to provide more material for microdiamond sampling with the aim of improving sample representation and possibly also for local estimation later in the evaluation sequence.

When sampling is in the final evaluation stages, sufficient data must be available to enable resource block modelling for mine planning optimisation exercises.

2.9 Kimberlite sampling

Prospecting leads to the discovery of potentially mineable deposits. Sampling confirms the nature of the discovery as potentially diamondiferous and is followed by systematic examination of the deposit to establish its potential value.

Major kimberlites were mined as recently as 20 years ago with ore reserve information 'less than considered a desirable minimum' at the time. [45]. This was only possible because the deposits were far from marginal. Shareholder protection became much more of an issue only after the 6 Billion Dollar gold fraud by the Bre-X group of companies that shocked the mining world.

Diamonds are valued by size and the reward lies in finding higher valued large stones. Commercial diamond recovery is normally focused on stones larger than +1mm square mesh (0.01057 carats) or more, but rarely lower. Smaller stones present challenges with respect to recovery. In view of this, conventional sampling was never really focused on diamonds in the -0.5mm size range.

For many years microdiamonds merely provided an indication of diamond content. As such, little was done to introduce proper microdiamond sampling principles. With the emphasis remaining on +1mm diamonds for diamond content assessment the development of small stone sampling and evaluation techniques was neglected.

Without application of basic sampling rules initially, most of the microdiamond sampling material extracted must be regarded as specimens rather than samples. Valuable information with respect to in situ diamond size distributions was nevertheless obtained and micro and macrodiamonds were successfully correlated. This happened in De Beers to the extent that the Kimberley Acid Laboratory (KAL) was maintained and later replaced by a facility with larger capacity, mainly to accommodate reconnaissance and exploration sampling programs.

The situation in which microdiamond sampling was not used to its full extent in sampling campaigns lingered until the early 2000's. In 2003 a Research unit was established by De Beers with the specific purpose of improving deposit evaluation. One of the five components of the unit focused on microdiamond sampling and estimation of diamond content in primary deposits.

Diamond revenue modelling, requiring large numbers of macrodiamonds, was indirectly affected by not making use of small, more abundant diamonds, as it is possible to establish a reliable diamond size distribution early in a sampling program based on microdiamond sampling.

With a reliable estimate of the diamond size distribution model it is possible to model diamond content almost entirely on the basis of microdiamond sampling. Large diameter drilling and sampling for +1mm diamonds is required mostly for diamond valuation and for confirmation of the associated diamond size distribution. Both sets of stones are vital for evaluation, but they demand different levels of interest at different sampling phases.

The benefits associated with microdiamond sampling do not only relate to sampling costs. Core drilling provides better quality geological information and provides information for other purposes such as pipe geology, pipe geometry, ore dressing and geotechnical studies simultaneously. Careful management of drilled core provides opportunity for further sampling many years after completion of a drilling program.

Since the early eighties comprehensive macrodiamond sampling programs have been carried out to estimate resources in Botswana and South Africa. Estimation was done to 200m depth, later to be extended to 400m and deeper. If the techniques discussed in this thesis were available at the time of discovery and during the development of these major kimberlites, resource evaluation could have taken place more cost effectively. Instead, sampling had to take place by means of various types of large diameter percussion drilling, typically to develop local diamond content estimates in a 3-D block configuration.

At that time microdiamond sampling was done at De Beers mostly as part of exploration and reconnaissance sampling programs. At operating mines microdiamond sampling was done to examine the correlation between micro and macrodiamonds, mainly for research purposes.

As a consequence of this research the resource extension programs that are currently being implemented at the three major Southern African kimberlites (Jwaneng, Orapa and Venetia) have been making extensive use of microdiamond sampling and evaluation methodology [18].

2.9.1 Sampling phases

Mineral resource sampling is divided into three main phases. [45]

The reconnaissance_phase includes initial work to establish the nature of the anomaly, whether it is kimberlitic and diamondiferous.

Initial indications of diamond content, the size of the deposit, the presence of overburden and other matters relating to mining of the deposit are considered in the sampling program. Basic sampling principles should apply from the outset of the reconnaissance phase. A single piece of rock may be an interesting specimen from the local area and even a single, well excavated sample from the deposit may come from a domain that does not represent the deposit at all.

This phase may only set the scene for further work but it is probably the most critical stage of sampling. This stage is the most likely to walk away from a potential mine - a mistake that can only be avoided by proper sampling. The odds are against a deposit being economically viable – of the more than 4000 kimberlites known to exist, some 500 are known to contain diamonds, 60 have been mined and fewer than 20 have contributed significantly [5]. If the opportunity is there to find one, then it must be taken.

This phase of sampling should therefore inevitably be weighted towards making a Type II statistical error – to continue sampling a non-viable deposit.

The exploration phase is aimed at establishing estimates for all the parameters required for mining. Sampling is about making progress either towards mining feasibility studies or to walk away from the deposit with confidence.

The exploration phase may consist of more than one sampling campaign, depending on the complexity of deposit geology and the level of uncertainty that still exists. This phase takes diamond content and revenue estimates to a level of confidence that would allow a decision to continue with or abandon a project and will have to include bulk or mini-bulk sampling for macrodiamond recovery. The purpose of this sampling phase is to provide a preliminary economic assessment (PEA). According to industry regulations a positive PEA is required before the deposit can be classified as Inferred resource.

Advanced sampling for Feasibility or pre-feasibility studies commences when the outcome of the PEA is positive and the decision has been made to perform sampling that may move the deposit into a higher resource category. The focus is on developing a resource that can be used to perform mining feasibility studies.

During this phase every aspect relevant to the mining feasibility still subject to an unacceptable level of uncertainty must be taken care of.

Sampling campaigns follow the three phases without the existence of a strict time line distinguishing them from one another. Furthermore, each phase could be subdivided into different stages in accordance with the progression of deposit evaluation.

2.9.2 Microdiamond sampling

During the early stages of sampling the underlying focus is on obtaining information with respect to the next step in the evaluation sequence, whether it is to walk away from the deposit or to design a more detailed next sampling phase. From the outset there is a balance between resources applied to reach a decision and the potential loss if the decision turns out to be incorrect.

Inadequate sampling will most likely lead to bad decisions, whether it is to do more sampling or to walk away from the deposit. Over-sampling on the other hand, is a waste of resources that could otherwise have been applied to the next sampling phase or to another sampling program.

It is costly not to mine a deposit which could have been mined profitably or to extend a sampling program that could have been terminated earlier. In the first case the potentially substantial loss equals everything lost by not owning the mine.

Potential losses in the second case is not only the direct cost of unnecessary additional work, but also the loss incurred by not attending to a source that could have been found and advanced in the meantime. Although these losses are difficult to quantify, the magnitude of the potential financial damage caused by irresponsible sampling is enough to motivate extreme care when designing a sampling program.

The following statement describes the role of sampling and underlines the importance of doing it correctly [27]:

"Quality estimation is a chain and sampling is its weakest link"

The key elements in sampling are sample size and sample representivity, which cannot be achieved by examining a single 'part' of the deposit. A sample will be composed of a number of fractions or subsamples.

Sampling is the science of selecting a fraction of a batch of matter to represent the whole batch of matter on which quality estimation is carried out instead. [27]

The focus is on sampling in the form of small fractions of kimberlite from a deposit in such a way that sufficient numbers of diamonds are obtained to represent diamond content in the deposit at acceptable levels of confidence.

The convention in the text is that a subsample or aliquot may be the 'small part' contributing to the combined large sample. The small parts are referred to as aliquots when a batch of material is split into smaller parts to comply with the maximum size of a treatable batch at the lab. The distinction will be highlighted when it matters.

Figure 2-12 illustrates the process of logging and subsample selection from drill core laid out in core boxes. Note the kimberlite weathering.

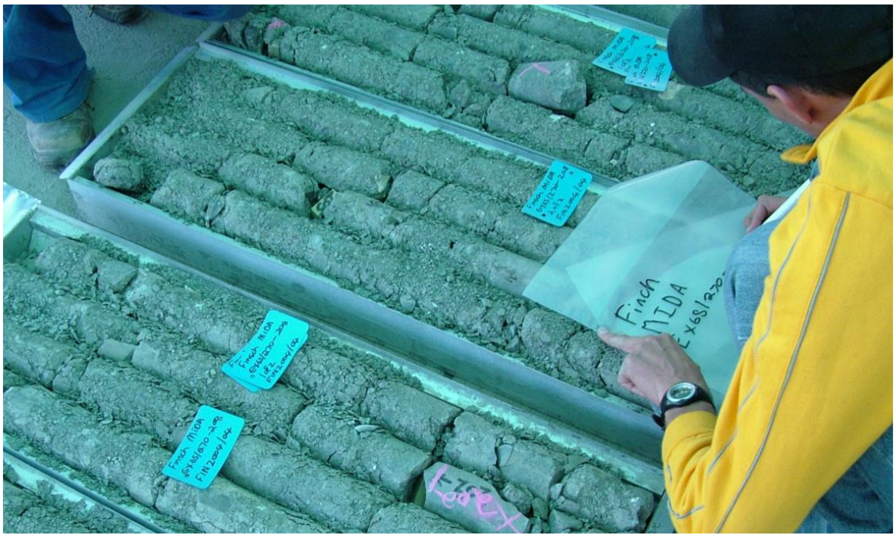

Figure 2-12 : Microdiamond Subsample selection

2.9.2.1 Sample components

For diamond concentration the critical sampling component [44] is the number of diamonds per weight or volume. For diamond size distribution the critical component is diamond size. The active components of a sample are the diamonds, the kimberlite and all non-kimberlitic inclusions contained in the sample. These components define diamond content, which comprises carat weight of diamonds by size class.

The purpose of sampling is to characterise the diamond assortment contained in the kimberlite deposit, with respect to diamond concentration, diamond size and diamond value. Although it does not form part of the major objective of sampling for diamond content, value is included to emphasize the role of the distribution of diamond size with respect to diamond revenue. Individual diamond size and value are important with respect to what they contribute towards the collective character of the diamond assortment.

When the level of kimberlite dilution (or contamination by non-kimberlitic material) needs to be estimated, the presence of non-kimberlitic material is added as critical component of sampling.

The following variables are measured and recorded to characterise diamond content and value:

- Subsample size in terms of weight in kg (concentration)
- Number of diamonds recovered above a bottom screen size (concentration)
- Individual diamond weight in carats or mg (size distribution)

- The mm sieve class the diamond belongs to (size distribution)
- Individual diamond values in USD per carat (diamond value, not for microdiamonds)
- Non-kimberlite inclusions as a percentage of the sample (concentration)

It follows that a sample will consist of a number of subsamples, composed in such a way that, collectively, they are representative of the domain considered.

2.9.2.2 Sample treatment

Conventional crushing and separation methodology is not suitable for microdiamonds as it is difficult to separate kimberlite particles that contain microdiamonds from barren particles. Microdiamond treatment takes place by dissolution of kimberlite by caustic fusion or by means of acid dissolution. Recovery takes place to a bottom cut-off limit of 0.075mm or ~0.0000018carats.

Acid dissolution

Microdiamond subsamples weighing approximately 20kg are treated by means of acid dissolution. One of the components in the process is Hydro-fluoric acid, which is extremely dangerous.

The process begins with crushing of the sample material to -6mm undersize followed by a process of attritioning to remove up to more than 90% of the sample in the form of -0.075mm underflow. The product is treated with Hydrochloric acid to remove carbonates and is followed by Hydrofluoric acid to remove silicates. Aluminium tri-chloride is added to remove any precipitation that formed around the remaining particles. Final reduction takes place by means of microwave heating and hydraulic pressure. The residue is hand-sorted and the recovered diamonds are weighed and individually characterised.

Caustic fusion

The use of Caustic Fusion (CF) is more widespread, but this does not imply that CF is not dangerous. Work experience with data from both treatment procedures has not suggested any preference, as both methods yield satisfactory results. Etching and damage of diamonds are eliminated due to the high resistance of diamonds to caustic soda. Treatment produces concentrate from which liberated diamonds can be readily extracted by microscopic examination. Material is poured into a kiln before caustic soda is added and heated to 550ºC and maintained for 14 hours. The molten caustic soda is then screened using a bottom screen of 0.075mm (or higher if specified).

The residue is separated from the Caustic soda by washing in hydrochloric acid leach and hot water baths. Dried residue is examined a minimum of two times and diamonds are recovered by means of binocular microscope.

2.9.2.3 Other treatment aspects

The weight of the sample on receipt prior to any treatment preparation, as well as the dry weight, is recorded. The latter is used to calculate diamond concentration and grade. Sample weight reduction after caustic fusion could exceed 99.9%.

The standard treatment procedure varies according to specific requirements to improve the quality of the recovery process. For instance, a kimberlite type may contain a substance that is more difficult to dissolve, which requires specific steps to be taken, or the crusher aperture may be increased if it is known that large microdiamonds are likely to be recovered.

An optimal weight of material that can be effectively dissolved 'per pour'[15] is determined by the lab. Weight units of 6kg and 8kg have been used for caustic Fusion.

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[15] Each time a kiln is filled with caustic soda

It is preferred that sample material is not crushed prior to treatment. This is the case at most facilities using Caustic Fusion where material is broken into smaller pieces. When material is crushed to a pre-determined aperture, breakages may occur which render a subsample useless.

Diamonds from both treatment procedures are examined and if too many broken fragments occur the subsample is rejected.

For quality control purposes synthetic diamonds are added to the material prior to dissolution or fusion. Upon recovery all synthetic diamonds are identified and stored, including diamonds that may have been released from diamond drilling. Recovered natural diamonds are separated into 13 sieve classes by screening. Each diamond is numbered, weighed and stored on a sample card as shown in Figure 2 13.

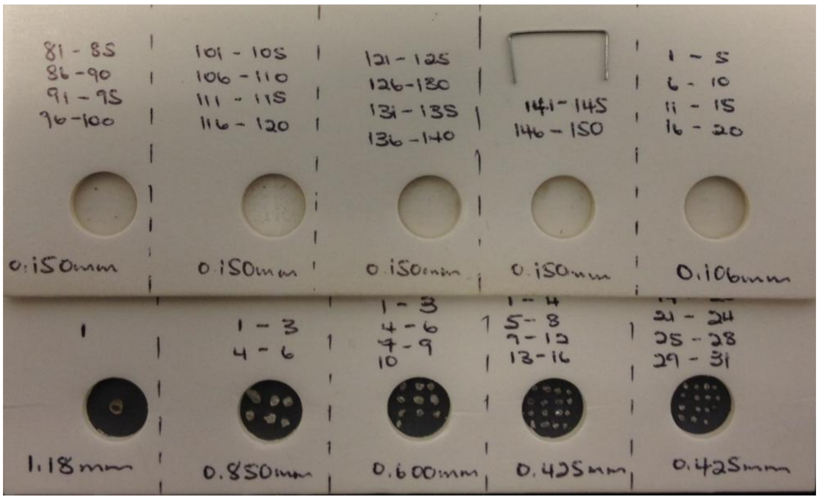

Figure 2-13: Storage of microdiamonds on sample card by size class. Diamonds are numbered. The smaller sizes are too small to be visible in the picture.

Colour, clarity, and morphology of each diamond is determined and reported. Some Companies measure the longest perpendicular dimensions (X Y and Z) of each diamond to be used for calculation of diamond weight, whereas De Beers has the technology to weigh each stone individually down to 75 microns.

Residues and recovered diamonds are stored and kept.

2.9.2.4 Individual stone weights and diamond sieves

Individual stone weights are recorded for all diamonds in a sample. In the case of large production parcels the stones are initially sieved into size classes and weighed for purposes of auditing and grade control.

The number of diamonds recovered per subsample is not too large for individual stone weights to be recorded from the outset. Sophisticated weighing facilities exist for commercial diamonds, but microdiamond sampling methodology inevitably requires more sophisticated techniques to provide reliable stone weight data.

Sieving and weighing of such small particles is problematic. In the industry all diamonds above 0.3mm are individually weighed. Stones below this size are individually measured and weighed in small groups of say 20. Individual three dimensional size measurements combined with the group weight are used to convert each stone measurement into a stone weight.

De Beers has developed technology allowing individual stone weights down to the +0.075mm size fraction (~0.0000018 carats). [26] However, individual diamond weight is of lesser importance when diamonds have been sieved into mm size classes.

The use of diamond sieves to classify diamonds in size categories simplifies commercial size diamond valuation and provides a convenient method of dealing with the large numbers of stones during production and sampling. Different commercial size breakdown schemes exist. Any size breakdown may be used for diamond content estimation, but the convenience of keeping in line with industry is obvious.

If sampling yields stones below the commercial bottom cut-off size, standard Tyler or other mesh sizes may be used to classify the stones into size classes. Diamonds may be physically screened into size classes or when individual stone weights are known, they may be assigned to size classes on the basis of class limits expressed in carat weight.

The standard DTC size breakdown is popular for diamonds above 0.5mm square mesh screen size. Industry specific size classes are defined in terms of equivalent sieve apertures, ranging from 1mm to roughly 10mm square aperture. An example of results for three microdiamond subsamples is given in Table 2-2. The table shows all the data relevant to each sample, with stone frequencies summarised per size class.

Table 2-2 : Example of Microdiamond sampling results in size classes

Subsample ID		1	2a	2b
Hole ID		H_00	H_00	H_00
Form		CORE	CORE	CORE
From (m)		48	88	88
To (m)		50	90	90
Rock Type		Kimberlite	Kimberlite	Kimberlite
Litho-facies		type 1	type 2	type 2
Subsample weight (kg)		18.19	17.8	17.8
Size class	Class lower limit in carats	Number of stones		
c13	0.0017783	0	0	0
c12	0.0010000	0	0	0
c11	0.0005623	1	1	0
c10	0.0003162	0	0	0
c9	0.0001778	1	0	1
c8	0.0001000	6	4	0
c7	0.0000562	4	5	6
c6	0.0000316	21	9	9
c5	0.0000178	17	11	13
c4	0.0000100	10	3	6
c3	0.0000056	4	1	3
c2	0.0000032	2	1	1
c1	0.0000018	0	0	0
Total stones		66	35	39

Individual stone characteristics are listed for some of the stones in Table 2-3.

The information is recorded to enable removal of synthetic stones, to observe the number of fragments in a sample and for other possible investigations that may require stone characteristics, like testing for homogeneity of diamond populations.

Table 2-3 : Example list of Stone characteristics

Aliquot	Sample	Carat weight	Shape	Colour	Remarks	Inclusions
1	aaal763	0.000645	Maccle	Brown		Black inclusions
1	aaal763	0.000105	Octahedron			Black inclusions
1	aaal763	0.000058	Dodecahedron			Black inclusions
1	aaal763	0.000550	Dodecahedron			Black inclusions
1	aaal763	0.000750	Octahedron			Black inclusions
1	aaal763	0.014215	Octahedron			Black inclusions
1	aaal763	0.000035	Complex crystal		Broken stone	Black inclusions
1	aaal763	0.000051	Octahedron		Graphite coated	
1	aaal763	0.000034	Cubic	Light brown		

2.9.2.5 Sampling Protocol

A sampling protocol is drawn up prior to commencement of microdiamond sampling in order to ensure that the same sampling rules will be applied during the entire duration of the sampling campaign.

A protocol is required for every campaign and the following items are listed as illustration:

Sampling method and collection:

1. In the case of a kimberlite pipe a suitable drill-hole configuration must be selected to attain maximum coverage of the apparent pipe outline, but still ensuring that the pipe will be intersected with every hole. At least three holes should be drilled initially.
2. Nine 16kg subsamples are to be taken from each hole, three from the top, middle and bottom of a hole. If subsamples are to be split into aliquots to cope with laboratory constraints, the splitting should be done at the laboratory and sample integrity must be maintained.
3. The standard amount of material advised for the first batch of subsamples must be approximately 432kg, comprising 27 x 16kg subsamples. This may change if more than one domain is detected. If the treatment facility makes provision for 20kg subsamples the subsample size may be increased to 20kg and the number of samples per hole may be reduced to 6.
4. The length of core required to form approximately 16kg (or 20kg) of material must be calculated and used to demarcate core sections for sampling.
5. A subsample may be shifted to avoid intersecting more than one domain.
6. In the case of bedded kimberlite each bed must be regarded as separate domain if possible.
7. The subsample must be logged completely and the percentage inclusion of non-diamond bearing material recorded.
8. The entire drill-hole core should be logged and the percentage dilution calculated.
9. The core should be brushed off to remove synthetic diamonds from core drilling, if possible.
10. A core section to be selected as subsample may be moved to maximise the amount of kimberlite in the subsample only if the entire drill-hole core is logged and waste inclusions determined.
11. A photograph of every subsample must be taken in the core box before removal, as shown in Figure 2-14.

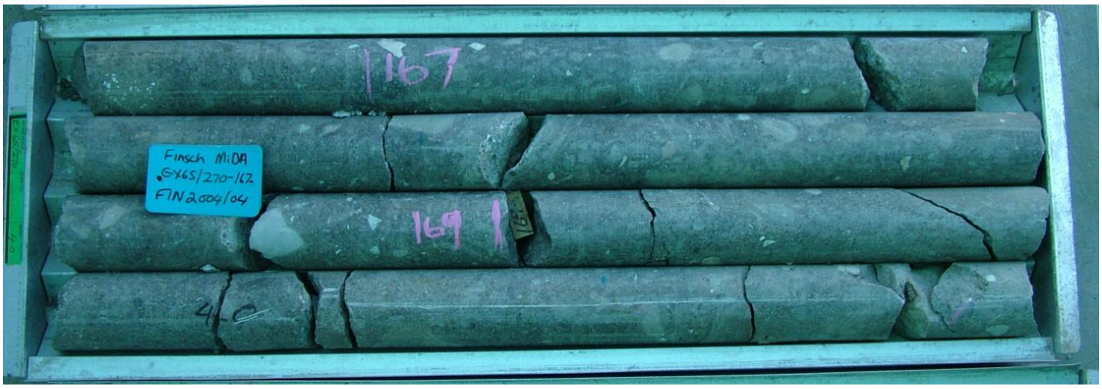

Figure 2-14 : Picture of microdiamond subsample in core box

12. A 30cm section adjacent to the subsample should be used for density (Sg) determination.
13. Another complete subsample section should be demarcated adjacent to the section collected and kept for auditing purposes. Other equidistant sections could be demarcated for possible use later in the sampling program.
14. Subsamples must be sealed and recorded with seal number shown on photograph of core box;
15. In the case of a dyke a few holes along strike can be drilled or samples may be excavated from surface and near surface. The other sampling issues mentioned above must be complied with where applicable.

Variables and data collected:

The following data is recorded:

1. Date and other administrative detail;
2. Unique seal number to identify subsample;
3. Section 'from' and 'to' location in meters down the hole;
4. Bagged section weight in kg;
5. Percentage waste inclusions to estimate subsample dilution;
6. Sample lithology and
7. Number of diamonds - to be added after recovery;
8. Individual diamond characteristics, including weight in carats or mg and sieve class that contains the diamond;

Handling of data and sampling material takes place as follows on site and at the laboratory:

1. An electronic data base is created;
2. Basic sample data is recorded;
3. Sample consignment is noted;
4. Subsamples made up in consignment for dispatch to laboratory;
5. Subsample is dried and dry weight is recorded at the lab;
6. Subsample is acid digested and residue weight is noted;
7. Residue is sieved into mm sieve classes;
8. Diamonds are hand sorted and weighed individually or by sieve class;
9. Spikes[16] are removed and counted;
10. Diamonds are individually classified by morphology, colour and inclusions;

[16] Particles added during processing to audit recovery of diamonds.

11. Diamonds are mounted as per lab procedure for storage and visible examination on sample cards.
12. Results are reported and diamond data is consolidated with sampling data.

Information pertaining to aspects of the project other than diamond content will also be recorded and are not mentioned in this text.

2.9.2.6 Uncertainty

A specific level of uncertainty is associated with a given sampling program. Monte Carlo type simulation can be done to assess uncertainty levels.

Knowledge about the deposit may be combined with appropriate assumptions to simulate a realistic virtual deposit representing the one to be sampled. Application of different sampling programs to the simulated deposit and using the results in an estimation exercise will yield different sets of results. Examination of the different sets of results in a risk assessment exercise could assist in developing an optimal sampling strategy.

There is a danger that the holes to be drilled may miss a viable domain. Some known kimberlites could have been missed even with sampling from more than one drill-hole. For example, during an initial sampling program four large diameter holes drilled into a kimberlite now being mined were essentially barren.

Diamond content may be estimated zonally by domain or locally in terms of a block model. Confidence in the models for diamond size and concentration increases as more sampling data becomes available.

Sampling density and the level of confidence that may be attained are directly related. When the concentration of diamonds is low, more samples will inevitably be required just to obtain enough stones for size modelling as is illustrated in the case studies.

Estimation of the diamond size distribution is more demanding than the estimation of diamond concentration. The number of subsamples available to estimate concentration determines the level of confidence in the estimates.

The nature of the size distribution will determine the number of stones required for size modelling and, as a consequence, also the number and size of samples required for attaining a given level of confidence.

The locations of drill-holes and samples must ensure that sampling results are unbiased.

2.9.2.7 Consequences of the use of microdiamonds for sampling

The use of microdiamond sampling for diamond content modelling introduces a new sampling approach which differs significantly from conventional sampling for diamond content.

The earliest stage of deposit evaluation sampling is done by means of core drilling, which is relatively cheap and which provides high quality information on pipe geology, geometry and material density and simultaneously provides microdiamonds for diamond content estimation.

Thin core drilling is quick and cheaper than large diameter drilling. Difficult locations are easier reachable with lighter drilling tools, allowing angled drilling into deposits that may only be accessible with great difficulty otherwise.

2.9.3 Sampling Methods

Economic potential for a deposit relates to recoverable diamond content, which in turn relates to the size of the body and the grade and diamond liberation characteristics of the host kimberlite.

Cost is one of the most important considerations in the decision about the amount and type of sampling. The method of sample excavation will, to some extent at least, be determined by sampling needs at the time. The terrain, pipe geometry and the nature of the kimberlite material will also play a role.

Material representative of the host kimberlite is required to estimate diamond content and average diamond value. Ore dressing studies to enable decision making with respect to treatment and liberation parameters for diamond recovery must be done for feasibility studies. For this purpose material is excavated and presented for treatment in a manner resembling mine production.

Macrodiamonds are required as early as possible during sampling for preliminary estimates of average diamond value. Different sampling methods provide sampling material in different forms at different stages of sampling.

Core drilling is ideal for the first sampling stages. It provides core sections from depth for microdiamond sample selection and simultaneously allows early exposure of the complexity of deposit geometry and geology.

Bulk sampling and mini-bulk sampling by means of large diameter drilling and pitting or trenching are required to excavate sufficient quantities of macrodiamonds for diamond valuation when initial diamond content estimates are favourable.

All the methods of sample excavation and recovery are aimed at retaining diamonds in their in situ form. The first and most important requirement of the sample excavation method is that diamond damage is minimised to preserve diamond value.

Before the introduction of microdiamond methodology it was customary to begin a sampling program with surface pits or trenches, which immediately provides diamonds for valuation, unfortunately limited to the surface in the deposit.

For example, during the 1980's a deposit was sampled by means of a network of pits before commencement of a large diameter drilling (ldd) program. Diamond core drilling confirmed the extent of the body before the first ldd hole was drilled. A shaft was sunk to recover diamonds for valuation. Shaft and ldd samples were compared at depth to investigate possible changes in liberation characteristics of the material. The upper elevations of the body comprised of lower grade material, which did not favour trenching or pitting. This type of sampling gave access only to the lower quality material not representative of the pipe at all. The first major reliable resource estimate was based on the outcome of a large diameter drilling program many years after the discovery of the deposit. Drilling took place by means of 50cm diameter percussion drilling to a depth of 200m, first on a 150x150m grid and subsequently reduced to 50 x 50m. Drilling took place by means of a cable tool and samples consisted of material from 5m or 6m drill-hole sections. The drilling process was slow, drill-hole break-back complicated the determination of sample size and resource estimates were subject to a high level of uncertainty.

Modern large diameter drilling takes place by means of air or fluid assisted reverse circulation drilling of holes with diameters of up to 50cm and more. Core drilling with core diameters of up to 12 and 20cm are drilled for resource estimation. Thin core drilling combined with large diameter core or percussion drilling is capable of providing all the information required for high confidence resource modelling.

Combining core and percussion drilling provides microdiamonds for diamond content estimation and a parcel of macrodiamonds for valuation, and is accompanied by the geological signature associated with each sample for the development of a geological model.

Research suggests that an extensive 8-inch core drilling program with diamond recovery to +0.5mm, combined with microdiamond recovery to +0.075mm is capable of providing all the information necessary for detailed diamond content and value estimation. The intensity of the drilling program will depend on the nature of the diamond deposit and the required resource category.

3 Modelling kimberlite diamond content

Résumé

Deux modèles sont nécessaires pour décrire la ressource en diamants d'un gisement, le premier régit la concentration des pierres et le deuxième leur granulométrie.

La concentration des pierres est représentée par l'histogramme du nombre de pierres contenues dans les échantillons. Cet histogramme est modélisé par une loi discrète, à cela près quelconque.

La granulométrie des pierres est modélisée par une loi lognormale. Ses paramètres doivent être estimés de façon à rendre compte des données fournies par les échantillons. En raison de leur traitement, seules les pierres au dessus d'une taille critique (0.5mm pour les macroéchantillons et 0.075mm pour les microéchantillons) peuvent être récupérées, sans l'être de façon systématique (piégeage dans la gangue de kimberlite, acceptation par le tamis de taille critique). Certaines classes de taille sont ainsi affectées par ces pertes et doivent donc doivent être éliminées. C'est la raison pour laquelle une nouvelle troncature est appliquées au dessus de la taille critique initiale. L'estimation des paramètres lognormaux tient compte de cette troncature. Elle se fait selon une procédure itérative par simulations et adjustements successifs des paramètres jusqu'à ce que les lois tronquées des valeurs simulées et des données d'échantillons coïncident. Cette procédure permet d'intégrer les données provenant d'échantillons de grande taille avec leur contingent de macrodiamants.

Par combinaison de la concentration et de la granulométrie des pierres, on obtient la loi du nombre de pierres en fonction de leur taille, que l'on représente en coordonnées log-log (courbe LC). La plupart du temps, cette loi est modélisée à partir des microdiamants exclusivement.

Overview

Two models are involved for the amount of diamonds in kimberlite, one for the distribution of diamond size and another for diamond concentration. Combination of the two models leads to a distribution of diamond concentration with diamond size, represented by the log-concentration log-size model (LC-curve). Modelling is based on diamonds recovered from <u>microdiamond</u> sampling.

Distribution of diamond size is in accordance with the lognormal distribution. Size distribution modelling takes place for diamonds in situ and the model is suitably adjusted to represent

recoverable diamonds. Diamond concentration is measured in terms of sample stone counts represented in the form of a statistical distribution.

Sampling provides diamonds from the diamond population at fixed bottom cut-off size. Bottom cut-off in recovery takes place at screen sizes as low as 0.075mm for microdiamond sampling and 0.5mm for macrodiamond sampling. Not all stones that should be present in the bottom size classes are recovered, as some stones pass through the bottom screen because of their shape and some remain locked in rock particles that are discarded. Size classes affected by these losses have to be eliminated as modelling is based on size class frequencies that represent the in situ size distribution only. Truncation is therefore applied at a size above the bottom cut-off level.

The distribution of diamond size is determined by kimberlite domain. Diamond size is determined by establishing the parameters of a 2-parameter lognormal statistical distribution. To cope with truncation, modelling is done by means of simulation. Lognormal parameters are obtained by a process of iterative simulation and truncation until the resulting simulated diamond distribution corresponds with the truncated sample distribution. The methodology provides for the inclusion of diamonds from bulk sampling to populate size classes in the macrodiamond size range to confirm the models based on microdiamonds.

By incorporating a statistical model for diamond concentration a typical sample of diamonds is simulated. Parameter estimates for the model are only accepted if the size distribution and concentration of simulated diamonds compare acceptably with sampling.

Diamond occurrence is represented by a Cox Process. Diamond concentration is assumed to be spatially distributed as a generalised Poisson process with less stringent conditions.

3.1 Diamond occurrence[17]

3.1.1 Spatial aspects

Consider a kimberlite domain A, which could be a sample, a block, a lithological zone or any part of the deposit containing one type of kimberlite.

There are two variables of interest:

- The diamond concentration N(A), or the number of stones in domain A
- The diamond content W(A), or the cumulative weight of stones in domain A.

The dependence relationships between the two variables associated with identical or different domains is of interest and the variables are represented by means of a mathematical model.

At first the spatial distribution of diamond concentration is described using a preliminary model, namely the 'Poisson' process. This model turns out to rely on too stringent conditions and the more flexible 'Cox' process is considered as a simple generalisation of the Poisson process.

Under the supplementary assumption that different stones have independent sizes, the Cox process can also be used to model the spatial distribution of diamonds.

The images of diamonds in kimberlite shown in Figure 3-1 suggest the plausibility of such an assumption.

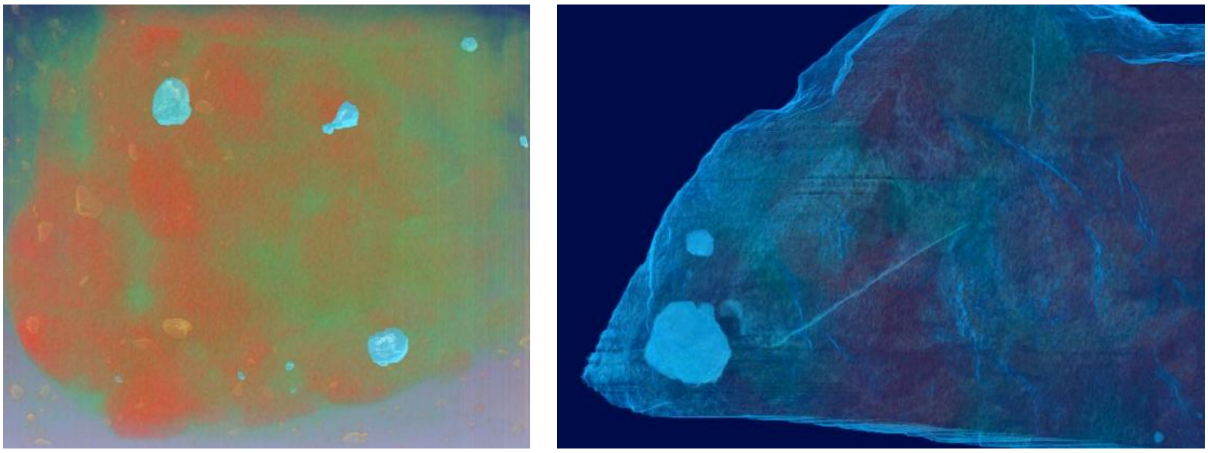

Figure 3-1: Microdiamonds in Kimberlite in the form of illuminated particles

3.1.2 Poisson Process

This model [32] is parameterised by a numerical function z, called the **intensity function or stone potential**. The integral of z over any domain A is given by

$$z(A) = \int_A z(x)dx$$

This is nothing more than the mean number of stones in domain A.

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[17] Under guidance of Lantuéjoul C.

More generally, the spatial distribution of a Poisson process is defined by the following two assumptions:

(i) If $A < \infty$, then the number of stones in A is Poisson distributed with mean z(A) and
$P\{N(A) = n\} = e^{-z(A)} \frac{z(A)^n}{n!}$, where n=0,1,2,…
If $A = \infty$, then $N(A) = \infty$.

(ii) The numbers of stones in pairwise disjoint domains are mutually independent.

Although these assumptions are not realistic they make the model tractable and in particular, the Poisson process satisfies the following property:

If N(A) = n, then the n stones are independently located in A, all having the same p.d.f f(x) given by $f(x) = \frac{z(x)}{z(A)} I_{x \in A}$.

Another interesting property concerns the covariance between the numbers of stones in two domains A and B, given by:

$$Cov\{N(A), N(B)\} = z(A \cap B)$$

If $A \cap B = \emptyset \; then \; z(A \cap B) = 0$, which implies that N(A) and N(B) are uncorrelated.

This result was already known as a consequence of assumption (ii).

However this is not what is observed in practice, therefore a more appropriate model like the Cox process is considered. [10]

3.1.3 Cox Process

This is a Poisson process with random intensity function or potential Z(A). [34]

Introducing a second level of randomness notably modifies the properties of the model. For instance, the distribution of the number of stones in domain A is now a mixture of Poisson distributions

$$P\{N(A) = n\} = E\left\{e^{-Z(A)} \frac{Z(A)^n}{n!}\right\},$$

This implies that the mean number of stones in A coincides with the potential of A,

$$E\{N(A)\} = E\{Z(A)\}$$

On the other hand, the covariance between the numbers of points in A and B is now expressed as a sum of two terms:

$$cov\{N(A), N(B)\} = cov\{Z(A), Z(B)\} + E\{Z(A \cap B)\}$$

This takes account of the structure of the potential and the Poisson location of the stones. In particular, in the case of disjoint domains A and B the covariance between N(A) and N(B) does not necessarily vanish, because the potential can exhibit long dependence.

A pleasant property of the Cox process is its stability under thinning. Suppose for instance that the stone weights are independently distributed with distribution function F. Then the point process comprising stones with weight exceeding w, is also a Cox process, with potential of domain A given by $\mathrm{Z(A)}(1-F(w))$.

Accordingly we have

$$E\{N_w(A)\} = (1-F(w))E(Z(A))$$

and

$$Cov\big(N_w(A), N_w(B)\big) = (1-F(w))^2 \;\; Cov\{Z(A), Z(B)\} + \big(1-F(w)\big)E\{Z(A \cap B)\}$$

This shows that thinning a Cox process reduces its variance while preserving its range.

As regards statistical inference of the potential from the concentration, two approaches can be made.

- In the stationary case with the diamond concentration available in a number of domains congruent to A:
  Then the distribution of N(A) is experimentally accessible. The distribution of Z(A) can then be retrieved from its generating function

  $$E\{\, s^{N(A)} \,\} = E\{\, e^{Z(A)(s-1)} \} \quad \text{for } 0 \le s \le 1$$

  The formula relates the moment generating function of N(A) and the Laplace transform of Z(A).

  For instance, if N(A) follows a negative binomial distribution with parameter α and proportion p, then

  $$P\{N(A) = n\} = \tfrac{\Gamma(\alpha+n)}{\Gamma(\alpha)n!} q^\alpha p^n\,, \qquad q = 1\text{-}p,$$

whereas Z(A) follows a gamma distribution with shape parameter α and scale parameter q/p.

$$f(z) = \frac{(q/p)^\alpha}{\Gamma(\alpha)} e^{-qz/p} z^{\alpha-1}$$

- More locally, if N(A) = n and if Z(A) is fairly constant in the vicinity of A, say Z(A) = z:
  Then, by the Bayesian approach using a non-informative prior distribution, the posterior distribution of Z(A) is Gamma with shape parameter n+1/2 and unit scale factor [29] [28]

  $$f(z) = \frac{1}{\Gamma(n+\frac{1}{2})} e^{-z} z^{n-1/2}$$

This approach was used in [15] to resize and reshape samples to make them congruent.

3.1.4 Towards diamond content

Assume again that the stones are located according to a Cox process with potential Z. Tractable solutions are obtained for diamond content in the realistic case where the stones have independent and identically distributed weights.

The following is explicitly obtained:

$$E\{W(A)\} = E\{Z(A)\}E\{W\}$$

$$Var(W(A) = E\{Z(A)\}E\{W^2\} + Var\{Z(A)\}E^2\{W\}$$

And generally

$$Cov\{W(A), W(B)\} = E\{Z(A \cap B)\}E\{W^2\} + Cov\{Z(A), Z(B)\}E^2\{W\}$$

For highly dispersed stone weight distributions the presence of the term $E\{W^2\}$ yields a large nugget effect that plays a detrimental role in the detection of the structure of the potential based on sampling data. This is the main reason why identification of spatial structure is performed on the sample stone concentrations rather than sample stone weights.

In the case where only stones of weight above w are recovered, by the stability property of the Cox process, the previous formulae remain valid, except that the potential must be multiplied by (1-F(w)) and the stone weight distribution must be replaced by a conditional distribution, owing to W ≥ w.

Finally

$$E\{W_w(A)\} = E\{Z(A)\}E\{WI_{W \geq w}\}$$

$$Var\{W_w(A)\} = E\{Z(A)\}E\{W^2 I_{W \geq w}\} + Var\{Z(A)\}E^2\{WI_{W \geq w}\}$$

$$Cov\{W_w(A)W_w(B)\} = E\{Z(A \cap B)\}E\{W^2 I_{W \geq w}\} + Cov\{Z(A), Z(B)\}E^2\{WI_{W \geq w}\}$$

3.1.4.1 Regionalisation

Simulation studies have shown that sample support size determines the level of confidence to be expected from sampling results. In the zonal sense it is clear that a minimum number of stones is required in order to ‘see’ a frequency curve, which is essential before one can expect to model a diamond size distribution.

In the local sense this is also true but with different consequences. Simulation studies show that when bottom truncation is increased and the number of stones in the samples decreases then spatial structure is lost. Nugget effect increases while sill decreases until only nugget effect remains in the variogram of stone concentration. In the case of diamonds it can thus be argued that if either sample support size is too small or bottom cut-off level is too high then spatial structure will not be visible.

The continuous size distribution implies that high frequency of microdiamonds in a sample signifies high stone concentration locally. If sampling results suggest the existence of spatial structure, then it means the data is suitable for local estimation.

Figure 3-2 shows two variograms constructed from the same sampling data truncated at different bottom sieve sizes. The variogram on the left is void of spatial structure for diamonds above +15 diamond sieve (+1.195cts), whilst the same sampling data at +3 diamond sieve (+0.0256cts) shows that diamond concentration is evidently strongly regionalised [13]

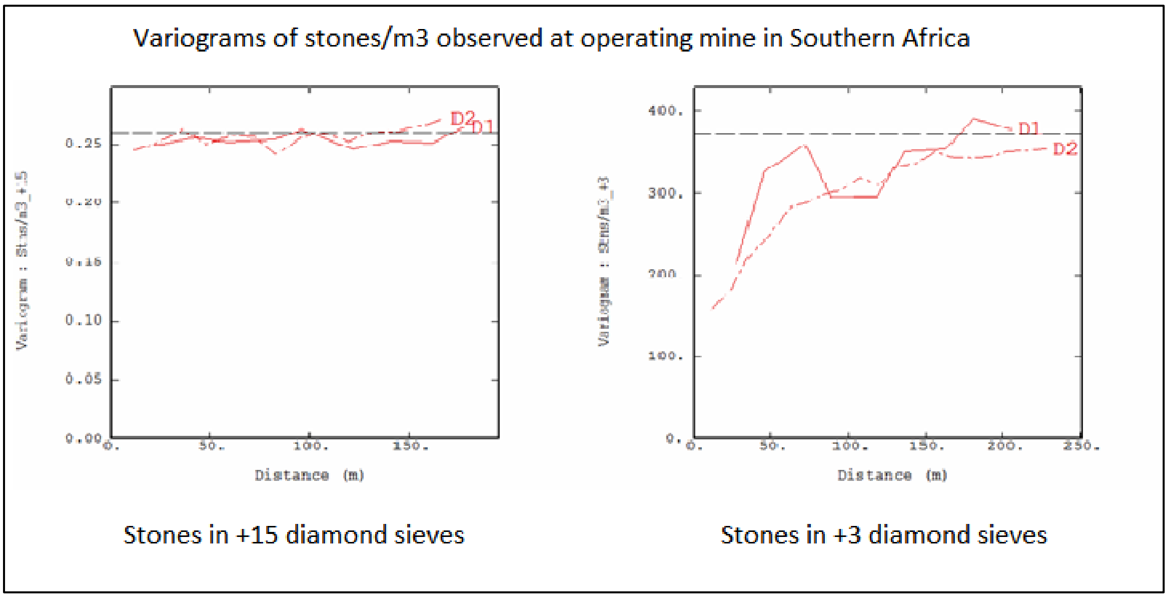


Figure 3-2 : Loss of spatial structure with increase in bottom truncation size

This will be the case across the diamond size range, including microdiamond sampling data from samples as small as 20kg. The implication is that unless the numbers of stones recovered from sampling is sufficient, spatial structure will not be detected and local grade estimates will not be obtainable from sampling, whether it is sampling for microdiamonds or macrodiamonds. (The probability of finding stones above cut-off size must not be negligible.)

3.2 Graphic modelling of diamond content

Microdiamond estimation methodology is mostly focused on minimal sampling results. Initial sampling requirements specify subsamples combined up to at least 400kg and often less. Local estimation based on microdiamonds is rare and is usually aimed at obtaining estimates by geological domain. Only by exception will sufficient microdiamond data be available for local estimation.

The methodology discussed in this section is aimed mainly on zonal diamond content, the amount of diamonds contained in a geologically homogeneous domain.

The graphic modelling and simulation approach and the emphasis on correct sampling procedures have been developed and propagated during this research project.

3.2.1 Organisation of sampling data

The diamond size distribution is one of the characteristics of the diamond assortment contained in a deposit which determines whether the deposit has potential to be mined economically. From the outset sampling is therefore focussed on this collective property of the diamond assortment.

Diamond size is the first component of diamond content and is unique per geological domain. It can be modelled on the basis of small samples, provided enough diamonds are available.

The statistical distribution of diamond size in a representative assortment has a positive tail and is represented by means of the lognormal distribution. This distribution is used in the thesis, but the assumption is not restrictive. It has been observed in practice that most primary diamond size distributions seem to follow the lognormal distribution

During mining and processing, diamonds have to be preserved in their particulate form. Broken diamonds are less valuable, but diamonds that remain locked in kimberlite have no (immediate) value. Furthermore, only diamonds above a given size can be economically recovered. Different sampling methods recover diamonds at different bottom cut-off levels. All sampling methods reflect an 'above cut-off' diamond size distribution. Modelling by means of simulation is used to emulate the effects of bottom cut-off on the diamond size distribution.

The quality of the sampling size distribution is determined by the number of diamonds in the sample and the size range covered. Sampling must deliver the diamonds contained in the sampling material in their natural size distribution otherwise no inference can be made with respect to the population diamond size distribution. A sample from which stones were accidentally or purposefully removed is unsuitable for diamond size distribution modelling.

In terms of diamond size distribution there is no distinction between micro- and macrodiamonds. The complete diamond size distribution can be derived from small stones if sufficient numbers of small stones are available across a large enough size range.

Deposits often present diamond populations with exceptionally high abundance of microdiamonds, but a diamond deposit has economic potential only if there is a reasonable probability of recovering diamonds of commercial size. In the early sampling stages this is one of the first properties of a deposit to be established and could lead to a decision to walk away from a deposit.

One of the most basic observations is that each domain in a kimberlite body is characterised by a unique size distribution and diamond concentration.

Microdiamond sampling provides a basis for diamond size distribution modelling, but requires methodology for modelling based on stones from the 'invisible' part of the full size complement in the source.

3.2.2 Lognormality of diamond size

[1]

It is assumed that diamond size has a lognormal distribution, which is in line with what has been observed in producing mines in the diamond mining industry for many years [26]. The most relevant properties of the distribution are discussed in this section in view of the role it plays in the research.

Other distributions have been considered in the literature but are not considered in this text. [5] [54]

Two aspects regarding crystal growth and decay support the lognormality assumption.

3.2.2.1 Exponential law of crystal growth

The Exponential Law of Growth states that the rate of crystal growth is directly proportional to the momentary volume of the particle or $\frac{dv}{dt} = kv$, where *v* denotes momentary volume (particle size), *t* is the time of growth and *k* is the velocity constant of growth [35].

It follows that $\frac{dv}{v} = kdt$, and therefore $\ln(v) = kt + V_0$, where V_0 denotes volume at time $t = 0$, resulting in the exponential law of growth $V(t) = V'_0 \, e^{kt}$ with $V'_0 = e^{V_0}$.

This is a simplistic growth model and suggests exponential growth from an initial volume of V_0, which could be interpreted as the germination volume.

The formulation is also known as the Logarithmic Law of Growth.

Its importance in this study lies with its application to the growth of crystals. It may be assumed that each ion in the surface of the crystal attracts a certain number of ions from the surrounding area. If this number is the same for all surface ions, it follows that the number of ions attracted in unit time will be proportional to the number of ions present on the crystal surface. The logarithm of crystal surface is linearly related to the logarithm of the crystal volume. The same argument can be followed with respect to crystal resorption.

The above equation can be rewritten as $ln\, V(t) = V_0 + kt$, which relates time of growth (t) to particle size (V).

If the time of growth (or decay) is assumed random, the result will be a random volume of particle, with volume log-linearly related to time of growth (or decay) as shown. As a consequence, if time of growth t is assumed normal, then the resulting volume distribution will be lognormal.

By the central limit theorem the sum of time durations will be normally distributed. The final size of the crystal will be the sum of growths during a number of time durations which, by the central limit theorem, will be normally distributed, explaining the log-normal diamond size distribution.

It is thus reasonable to accept that the nature of the chemical and mechanical processes involved in the process of diamond formation, transportation and deposition could contribute to the skewness of the size distribution of resulting sub-populations of diamonds in a kimberlitic resource.

The lognormal nature of diamond size distributions is reported in his Ph. D thesis by Davey [11] , referring also to other sources ([2], [58], [53] .

Further arguments for the positively skew size distribution of particles can be found in documentation on particle size distributions, described in [35].

3.2.2.2 Crystal growth and proportionate effect

One aspect of the lognormal distribution that relates with the idea of crystal growth is the proportionate effect. This is another explanation for the fact that the distribution of diamond size seems to be mostly lognormal

Assume that diamond crystal growth takes place intermittently and independently.

Suppose the initial crystal size is V_0 and that it is V_k after k steps and finally takes on value V_n after n steps. The change $V_j - V_{j-1}$ at step j is a random proportion of the value at step (j-1), namely V_{j-1} . If this is the case with crystal growth then crystal size is said to obey the law of proportionate effect [31].

Then

$$V_j - V_{j-1} = \delta_j V_{j-1}$$

$$V_j = \left(1 + \delta_j\right) V_{j-1} = V_0 \prod_{i=1}^{j} (1 + \delta_i)$$

Where $\{\delta_j\}$ are mutually independent and also independent of $\{V_j\}$.

After n steps the value of V_n is given by

$$V_n = V_0 \prod_{i=1}^{n} (1 + \delta_i)$$

It follows that

$$\ln(V_n) = \ln(V_0) + \sum_{i=1}^{n} \ln\,(1 + \delta_i)$$

By the Central Limit Theorem this sum is asymptotically normally distributed, implying that crystal size V_n is a lognormal variable. [1].

This, along with the Exponential Law of Growth gives some explanation for the lognormal nature of diamond size.

3.2.2.3 Relevant Features of the lognormal distribution

Definition

If variable X denotes the weight of a diamond then X is lognormal if $\ln\,(X)$ is observed to be normally distributed. Since diamond weight is a positive variable $\ln\,(X)$ will always be defined.

Therefore:

Consider variable X, where $0 < X < \infty$, such that variable $Z = \ln(X)$ is normally distributed with mean μ and variance σ^2 then X is a lognormal variable which is completely specified by the two parameters μ and σ^2. [1]

If the cumulative distribution functions of Z and X are denoted by H(z) and F(x) then

$$F(x) = P(X \leq x) = P\big(ln(X) \leq ln(x)\big) = P(Z \leq \ln(x)) \;= H(\ln(x)), \quad with\, x > 0\,.$$

Therefore in terms of the pdf

$$f(x) = F'(x) = H'(\ln\,(x) = \frac{h(\ln(x))}{x}$$

If h is the normal pdf with mean μ and variance σ^2 , then the pdf of X is

$$f(x) = \frac{1}{x\sigma\sqrt{2\pi}}\; e^{-\frac{1}{2\sigma^2}(\ln(x)-\mu)^2}\; for\; x > 0$$

The mean and variance of variable X is derived from this equation and are respectively:

Mean:

$$E(X) = e^{\mu+\frac{1}{2}\sigma^2},$$

Variance:

$$Var(X) = E^2(X)(e^{\sigma^2} - 1)$$

Note:

Diamond size distributions have been modelled by means of the three parameter and compound lognormal distribution [56]. In the research, the two parameter lognormal distribution has been found quite capable as modelling tool for diamond size.

The idea is to obtain estimates for the mean and variance for the size distribution of the in situ diamond size distribution, while sampling can only provide diamonds recovered above a given bottom cut-off size.

Quantiles

Using the notation above, we can write $X = e^{\mu+\sigma Y}$ where Y is a standardised Normal variable.

The q% quantile x_q for X is defined as

$$P(X \leq x_q) = q$$

It is related to the q% quantile y_q of Y by the formula

$$\frac{\ln x_q - \mu}{\sigma} = y_q$$

For standard normal variable Y we have $y_{.16} = -1, y_{.5} = 0 \; and \; y_{.84} = 1$ which materialises into

$$x_{0.16} = e^{\mu-\sigma} \; , \; x_{0.50} = e^{\mu} \; \text{ and } \; x_{0.84} = e^{\mu+\sigma} \; .$$

It follows that

$$\mu = \ln\left(x_{0.50}\right) \quad \text{and} \quad \sigma = ln\left\{\frac{1}{2}\left(\frac{x_{0.84}}{x_{0.5}} + \frac{x_{0.5}}{x_{0.16}}\right)\right\}$$

These expressions may be used to obtain estimates for μ and σ from a logarithmic probability graph depicting observations of a lognormal variable. However, they do not deal with the fact that the data may have been truncated as in the case of diamond recovery.

The issue of truncation has been addressed by Aitchinson and Brown [1], but the methodology was not adopted in the research because the lack of knowledge about the variable below the truncation level renders the method inappropriate.

The problem is resolved by making use of a simulation procedure, beginning with an initial set of parameters for the two-parameter lognormal distribution and following up with revised parameters until a satisfactory reproduction of the truncated size distribution is achieved by simulation.

Estimating a distribution that only partially reveals itself by sampling is the reason for using simulation and graphic representations in the application of this methodology.

3.2.3 Presentation of diamond size

3.2.3.1 Tabulation

In large diamond parcels it is impractical to determine the weight of each individual diamond. Large production or sample parcels are grouped into size classes by means of sieving. A diamond attaches to a size class on the basis of its size and shape. Class limits are determined in terms of mm sieve aperture and carat weight, and class widths are mutually different.

The log-probability presentation for diamond size distribution is attractive because it eliminates the need to transform weight to logarithmic weight and the use of the cumulative size frequencies is not affected by the non-uniform class widths.

Table 3-1 is an example of microdiamond data broken down into size classes and is used in all the illustrations given in this section. The table also shows a breakdown of bulk sampling results from the same source as well as recovery ratios as discussed in the paragraphs to follow.

Microdiamonds were recovered at a 0.075mm bottom cut-off size, while macrodiamonds from bulk sampling were recovered at a cut-off set at 1mm (+1 diamond sieve). The data in the table represent important issues regarding **discretisation** and **bottom truncation**.

Table 3-1: Microdiamond sample stone size breakdown. Estimated in situ frequencies for the bottom four size classes are shown next to actual recovery with estimated recovery ratio in the second-last column.

Class	Diamond Sieve	Lower critical weight (carats)	Microdiamond sampling 520kg (stones)	Microdiamonds with estimated losses added back in (stones)	Microdiamond Recovery ratio	Bulk sampling 635 tonnes (stones)
31	+23	8.036	**0**	**0**	**1**	**2**
30	+21	3.691	**0**	**0**	**1**	**2**
29	+19	1.918	**0**	**0**	**1**	**9**
28	+17	1.423	**0**	**0**	**1**	**8**
27	+15	1.195	**0**	**0**	**1**	**7**
26	+13	0.703	**0**	**0**	**1**	**75**
25	+12	0.523	**0**	**0**	**1**	**91**
24	+11	0.317	**1**	**1**	**1**	**272**
23	+ 9	0.179	**2**	**2**	**1**	**722**
22	+ 7	0.117	**0**	**0**	**1**	**989**
21	+ 6	0.0792	**1**	**1**	**1**	**1457**
20	+ 5	0.0485	**0**	**0**	**1**	**3047**
19	+ 3	0.0256	**8**	**8**	**1**	**3042**
18	+ 2	0.0186	**6**	**6**	**1**	**1043**
17	+ 1	0.01057	**17**	**17**	**1**	**841**
16	C16	0.010000	**2**	**2**	**1**	**0**
15	C15	0.005623	**46**	**46**	**1**	**0**
14	C14	0.003162	**33**	**33**	**1**	**0**
13	C13	0.001778	**76**	**76**	**1**	**0**
12	C12	0.001000	**95**	**95**	**1**	**0**
11	C11	0.000562	**116**	**116**	**1**	**0**
10	C10	0.000316	**173**	**173**	**1**	**0**
9	C9	0.000178	**226**	**226**	**1**	**0**
8	C8	0.000100	**257**	**257**	**1**	**0**
7	C7	0.000056	**309**	**309**	**1**	**0**
6	C6	0.000032	**441**	**441**	**1**	**0**
5	C5	0.000018	**451**	**451**	**1**	**0**
4	C4	0.000010	**389**	**649**	**0.9**	**0**
3	C3	0.0000056	**176**	**587**	**0.6**	**0**
2	C2	0.0000032	**41**	**405**	**0.3**	**0**
1	C1	0.0000018	**3**	**345**	**0.007**	**0**
			2,869	**4,246**		**11,607**

Discretization

The weight of the largest stone recovered is between 0.317 and 0.523 carats (+11 size class). In practice the table makes provision for 38 size classes with the largest class containing all stones larger than 150 carats, but can be changed depending on the nature of the size distribution.

Class notation is in accordance with the DTC sieve system above +1 diamond sieve for macrodiamonds and below this size in accordance with a system applicable for microdiamonds. In the table microdiamonds are classified into quarter log size classes on the basis of the carat weight for each stone.

For instance, in this configuration the lower and upper limits for class C2 are $(10^{-5.5}, 10^{-5.25}]$ and for class C16 $(10^{-2}, 0.01057]$ carats, where 0.01057 is the bottom critical size[18] for +1 diamond sieve.

At most laboratories microdiamonds are sieved into mm size classes down to a bottom screen size of 0.075mm. Actual lower critical sizes are extended down to the 0.075mm screen size, instead of using quarter log size intervals as shown in this table.

Class limits or critical sizes are determined empirically by sieving a representative diamond parcel and then weighing the individual stones by sieve class.

The distribution of individual diamond weights in two consecutive sieve classes shown in Figure 3-3 illustrates the point.

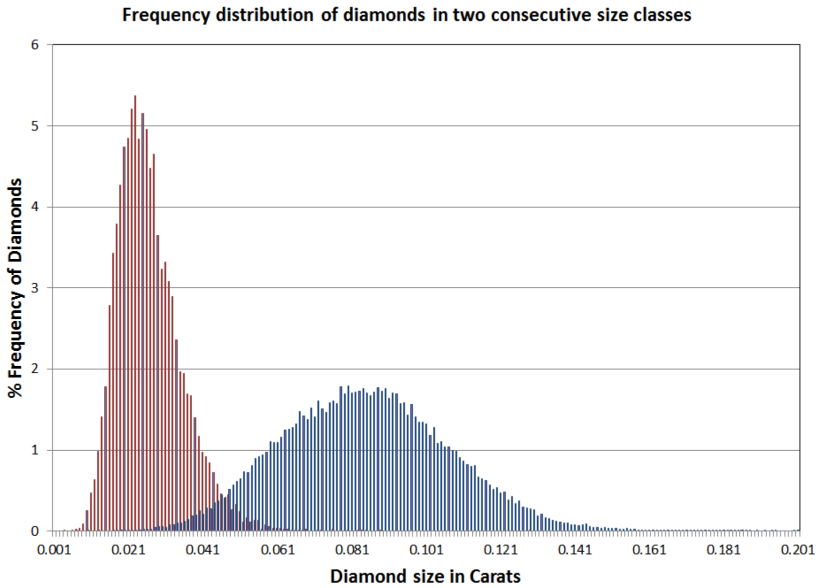


Figure 3-3 : Distribution of diamond size in two consecutive sieve size classes illustrating overlap caused by stone shape during sieving. This is the reason for having to define a critical diamond size when allocating stones to size classes on the basis of their weights.

[18] Critical size (weight) is a calculated weight that serves as class limit when allocating diamonds into size classes on the basis of weight instead of sieving them physically. It is defined as the weight of a diamond that will remain on the screen or pass through with equal probability.

Occurrence of diamonds in the overlap is due to the different diamond shapes in the assortment. Some of the heavier diamonds pass through the screen, while some of the lighter diamonds remain on top of the screen, thus occurring in the larger size class. The overlap is taken care of by accepting the lower critical weight as lower class limit for the size class. The lower critical weight for a size class is defined as the weight of a diamond that will remain on the screen or pass through with equal probability.

Diamond size classes are thus defined on the basis of a set of critical sizes corresponding to the sieve system in use. In theory the weights of all the stones occurring in a size class are assumed to fall between the lower and upper critical weights of the size class, with the upper critical weight for any size class being the lower critical weight for the next higher size class.

On this basis all calculations can be based on the assumption that stone weights are discretised into mutually exclusive size classes.

Bottom truncation

It is not possible to recover all diamonds during sampling or production. Small diamonds have little monetary value and tend to remain locked in small kimberlite particles. They are thus either locked in tailings particles that are floated out of the system, or if not locked, so small that they are lost as undersize during the recovery process. Microdiamonds are subject to the same constraints, except that there is no lockup in small kimberlite particles.

Application of a bottom cut-off has an effect on micro- and macrodiamond recovery and in both cases the effects occur near the bottom cut-off screen. Losses of small stones occur due to being 'locked' in larger kimberlite particles or simply because they are too small to stay on top of the bottom screen. In the first case small diamonds do not have enough weight to let their host particles sink in the DMS and are subsequently lost to tailings. In the second case diamonds that would normally belong to a higher size class on the basis of their weight, pass through the bottom screen as a consequence of their shape and is discarded with slimes and grits.

These losses are unavoidable and have to be assessed by means of practical testing. Recovery of these stones could be uneconomical and the presence of too much fines might hamper recovery of larger stones, effectively destroying value.

The example in Table 3-1 lists recovered diamonds by size class with recovery losses in the four bottom size classes.

Figure 3-4 shows the graph for diamond recovery truncated at size class C5 (0.000018cts).

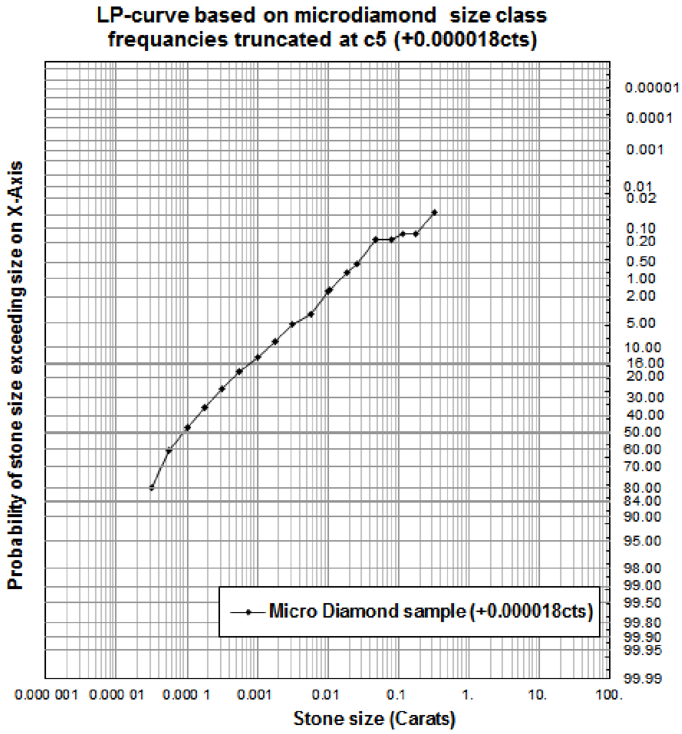


Figure 3-4: LP-graph for truncated diamond size distribution. Recovery is truncated at 0.000018cts to eliminate the effect of recovery losses in the bottom size classes. The curve is more linear than the curve based on all stones recovered shown in Figure 3-5.

Obtaining a size distribution model for diamonds in situ is part of the process of estimating diamond content. The in situ model exposes the effects of normal recovery losses that occur during treatment of microdiamond samples as well as during bulk sample treatment for macrodiamonds.

Possession of the in situ model enables optimisation of treatment procedures for small stone recovery. Without any idea of the quantity of stones lost and their sizes it is not possible to assess the financial impact of their loss.

Recovery ratios achieved in all size classes are included in Table 3-1 and shows the decrease in recovery ratio with the decrease in size class. Factors in the order shown in the table are (0.90, 0.60, 0.30 and 0.007). Up to four bottom size classes are typically affected, indicating recovery efficiency for diamonds in bottom size classes. The factors are derived during size distribution modelling and the procedure is discussed in section 3.2.4.

Similarly, in the case of commercial recovery of macrodiamonds the alignment factors will occur around the +1 to +7 diamond sieves, depending on the aperture size of the bottom screen.

Factors are observed near the bottom cut-off aperture and are specifically denoted as '**bottom cut-off alignment factors**' to distinguish them from other **modifying factors** that may be required to convert resource to reserve.

Diamond treatment processes are designed to optimally liberate diamonds without causing diamond damage. Every treatment process achieves a unique diamond recovery profile that determines recoverable diamond content. Bottom cut-off alignment factors depend on recovery process as well as underlying diamond size distribution and form an essential component of recoverable diamond content estimation. These recovery losses in microdiamond treatment were described as early as 1973. [26]

Furthermore, recovery methods used in sampling will not be the same as that to be used during production. The latter may not be known before the start of mine production and alignment factors are used to predict expected recoverable diamond content and value.

Quantifying bottom cut-off recovery losses

In situ class concentration for size classes affected by bottom cut-off losses can also be derived statistically when alignment factors are known.

Consider a population of stones containing an unknown number of stones in size class C. Let each stone in the class have probability p of being retrieved, with complementary probability q = (1-p) of not being retrieved. This is equivalent to stones in the size class being retrieved or lost due to bottom cut-off, where p is the class modifying factor. It is possible to estimate the number of in situ stones without making use of the LP-or the LC-curve.

Suppose n_0 stones are actually retrieved, then the in situ number of stones is equal to n with binomial weight

$$b_n = \binom{n}{n_0} p^{n_0} q^{n-n_0} .$$

Accordingly, the chance of having n stones in the class is

$$\frac{b_n}{\sum_{n \geq n_0} b_n} .$$

This reduces to

$$p_n = \binom{n}{n_0} p^{n_{0+1}} q^{n-n_0} \qquad n \geq n_0$$

Equivalently

$$p_n = p^{n_0+1} q^{n-n_0} \frac{\Gamma(n_0+1+n-n_0\,)}{\Gamma(n_0+1\,)(n-n_0)}$$

This equation can be interpreted by writing $n = n_0 + n'$ where n' is drawn from a negative binomial distribution with parameter equal to q and index equal to $n_0 + 1$. (n' is the number of stones that are lost before n_0 stones are retrieved, with $n = n_0 + n'$ being the total number of stones in situ)

In particular, the expected value of n is $n_0 + (n_0 + 1)\frac{q}{p}$.

With a unique p derived per size class this equation can be used to estimate in situ stone concentration for affected size classes. The greatest adjustment will be made for the size class with smallest probability of retrieving a stone. Note the equation works even if no stones were retrieved in the size class.

3.2.3.2 Cumulative probability distribution

A simple way of representing the diamond size distribution is by means of the cumulative distribution function in the form of a logarithmic probability graph. This has been used extensively prior to and during the early stages of the research and is still used at operating mines to examine the performance of recovery plants.

There is benefit in being able to visualise deviations from lognormality with the graphic method. An example is shown in Figure 3-5, based on microdiamonds recovered by means of microdiamond sampling.

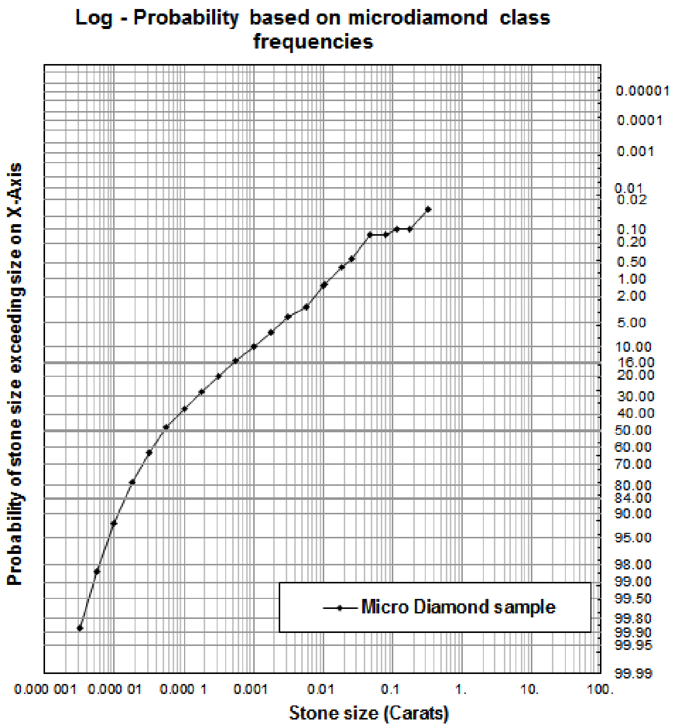


Figure 3-5: LP-graph for microdiamonds as recovered above 0.0000018cts (c1)

The reversed Y-Axis is used to conform to the convention used Industry wide. The graph depicts the probability of a stone exceeding a carat weight represented by the X-axis.

The horizontal lines at 16%, 50% and 84% are highlighted so that the percentiles of the logarithmic variable can be read. On the cumulative more than graph with reversed Y-axis the 16% probability indicates the 84% percentile and the 84% probability line the 16% percentile.

The associated size frequency breakdown of the microdiamonds from sampling is given in Table 3-1.

The curve shown in Figure 3-5 represents the cumulative number of diamonds per size class in the form of a LP-curve. It is invariant with respect to diamond concentration and only depicts the distribution of diamond size. If it is linear it suggests lognormality, otherwise not. The reason for the curve in this figure not being linear is due to recovery losses in the bottom size classes.

3.2.3.3 Log-concentration distribution

The second representation of diamond size is in the form of a plot of diamond concentration versus diamond size (LC-curve), with both axes log-transformed as shown in Figure 3-6.

Diamond concentration is expressed as stones per 100tonnes per unit size class to eliminate the effect of unequal class intervals. The microdiamond sample from Table 3-1 is depicted in the graph, with an indication of following a 2nd degree polynomial.

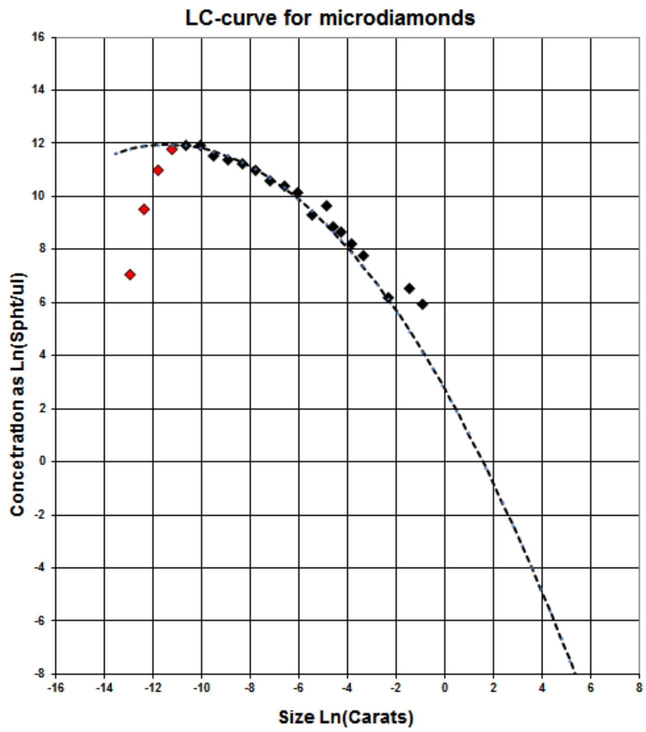


Figure 3-6: Combination of diamond concentration and diamond size distribution by means of LC-plot of sample recoveries. The four smallest size classes in the graph are affected by bottom cut-off recovery losses and do not fall on the 2nd degree polynomial that fits the rest of the sample points.

If the diamond size distribution is lognormal then the LC-curve will be represented by a 2nd degree polynomial, which is easily modelled. The model represents stone concentration per diamond size class and combined with average stone size by size class, allows estimation of diamond content at any cut-off size.

3.2.4 Lognormal Parameter estimation

Estimation of the lognormal parameters takes place by means of simulation, beginning with initial estimates that could be based on quantile values or guessed on the basis of experience and carried through by means of iterative simulation.

A large diamond parcel is simulated based on the selected size distribution parameters, truncated and compared with the actual truncated sample. Elimination of bottom size class frequencies affected by recovery losses enables comparison and modelling without any knowledge of the magnitude of the losses in sampling. (Alternatively instead of eliminating these size classes their frequencies may be temporarily adjusted by means of alignment factors observed in kimberlite elsewhere with similar bottom cut-off.)

Comparison takes place graphically as it is easy to see which parameter needs to be changed In order to approach the distribution of the sample parcel. A change in the slope of the simulated curve requires a change in variance of the simulated distribution, and to 'shift' the curve horizontally the log mean must be changed.

The steps followed in the procedure are as follows:

(i) Plot the sample log probability graph as shown in Figure 3-5;

(ii) Select a bottom truncation level, usually at least 4 size classes above the lowest size class;

(iii) Select (guess) values for the mean and variance of the in situ size distribution; these values may be derived by means of the quantile method discussed in section 3.2.2.3 as follows: Select modifying factors on the basis of experience with kimberlite at similar bottom cut-off and apply them to the bottom size class frequencies. Plotting the corresponding corrected LP-graph, shown in Figure 3-7, is a rough approximation of the in situ LP-graph. The quantiles derived from this graph provide a sensibly calculated 'first guess' for in situ mean and variance.

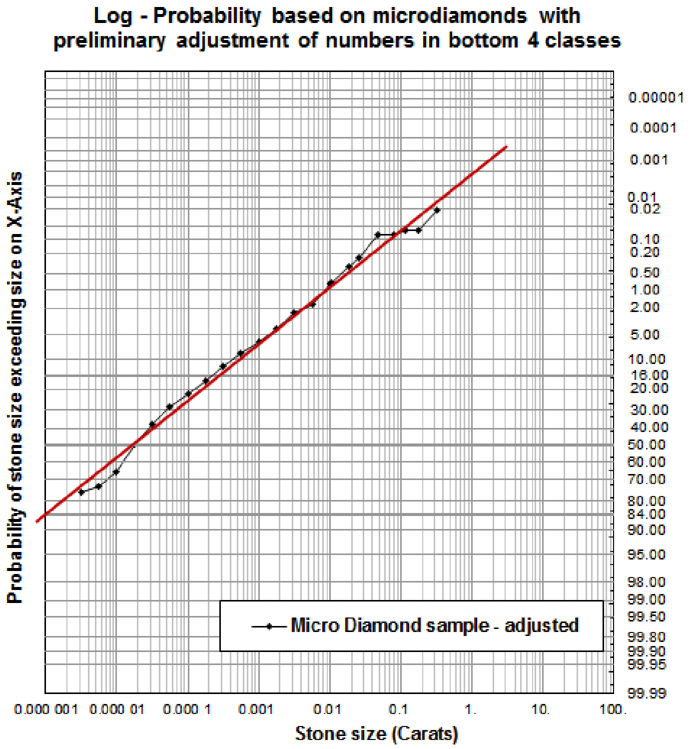


Figure 3-7: Log probability graph for adjusted size distribution as first approximation of the in situ size distribution. This is part of the process of approximating diamond concentration below truncation at 0.000018. The graph shown in Figure 3-4 only shows recovery above this truncation level and is not suitable to provide quantiles representing the in situ size distribution.

(iv) The quantiles are read from the X-axis on the graph in Figure 3-7 and are shown in Table 3-2.

Table 3-2 : Quantiles for calculation of lognormal parameters for first simulation.

Size distribution quantiles	Values read from Graph
$z_{.16}$	0.000001
$z_{.50}$	0.00002
$z_{.84}$	0.0003

(v) First estimates for in situ size distribution mean and variance are calculated from the quantile equation in section 3.2.2.3 and are shown in Table 3-3.

Table 3-3: Lognormal parameters for in situ size distribution

Parameter	Initial estimate	Final Values
Mean (μ)	-10.82	-11.45
Standard deviation (σ)	2.86	2.68

(vi) Draw 1 million lognormal values based on the parameter values and graphically compare the simulated distribution with the actual sample. Tabulate simulated stone weights into size classes and plot simulated and sampled <u>truncated</u> LP-graphs on one grid - both truncated at class C5 (+0.000018cts), as shown in Figure 3-8.

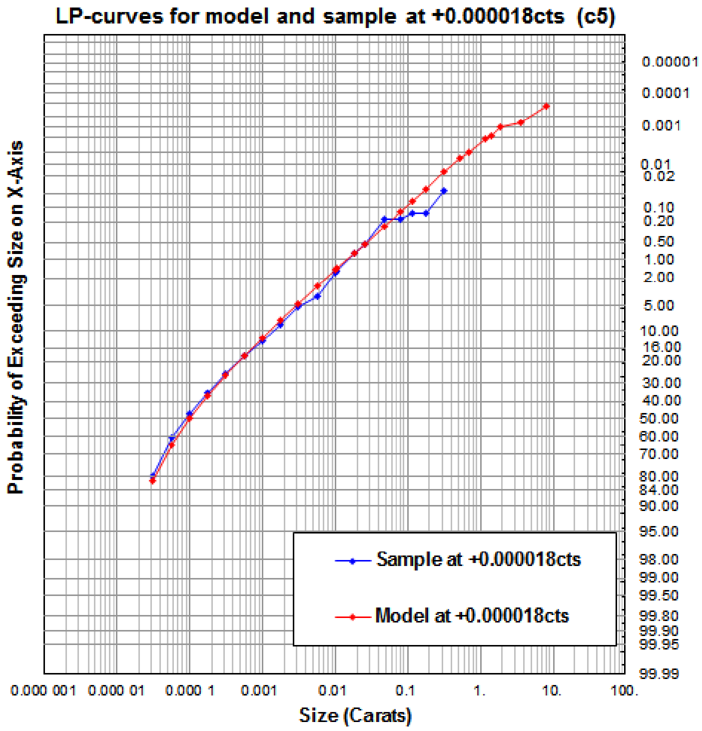


Figure 3-8: Truncated sample and simulated size distributions

.

(vii) Accept the simulation parameters if the two truncated graphs coincide;
(viii) Otherwise change mean and/or variance and repeat from step (vi)
(ix) Final values for the parameters are shown with the initial values in Table 3-3.

Size distribution modelling is initially based only on microdiamonds and will be confirmed by macrodiamonds whenever there is any reasonable chance of a deposit being economically viable.

A final comparison of sampled and simulated size distributions is shown in Figure 3-9.

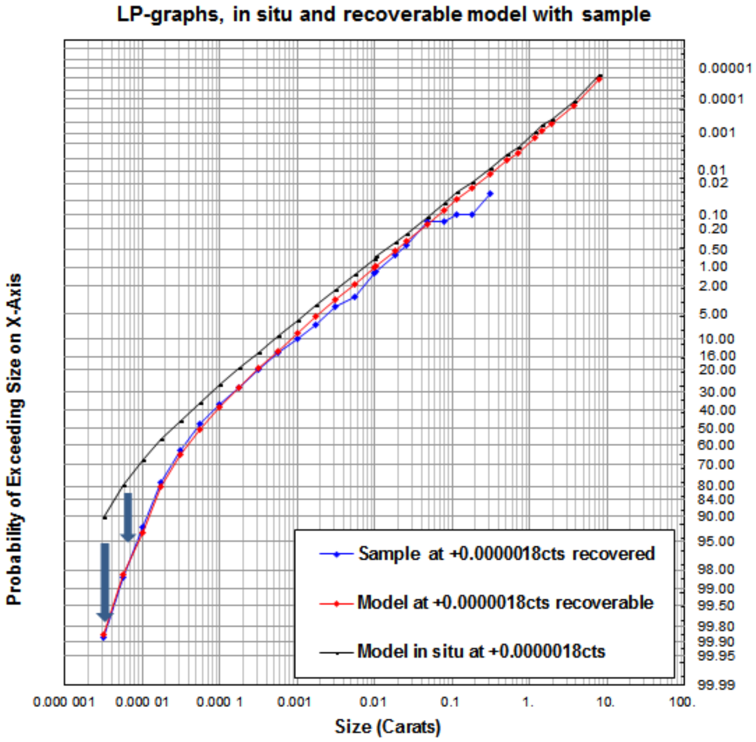


Figure 3-9: LP-graphs for actual sample diamond weights and simulated weights. The black graph represents 1 million simulated stone weights in the form of values drawn from a lognormal distribution with mean and standard deviation as shown in Table 3-3. The red graph shows actual recovered sample weights and the blue graph depicts in situ simulated parcel adjusted for recovery losses by means of alignment factors applied to the bottom 4 size classes as listed in Table 3-1.

Figure 3-9 shows the graph for actual sample recoveries, including the bottom four size classes that were affected by recovery losses. Concentrations for the four size classes of the simulated in situ graph are factorised to coincide with the values in the corresponding classes of the sample graph. These are the bottom cut-off alignment factors representing recovery efficiency relative to the 2-parameter lognormal in situ size distribution model. No other class values are adjusted.

Comments:

(a) The above procedure is described for a microdiamond sample with recovery above 0.075mm. The same procedure is followed for recovery at any other sieve aperture.

(b) Initial estimates for the lognormal distribution may be obtained by making use of Maximum Likelihood estimators. However, such an approach does not work with more than one cut-off level. For the determination of alignment factors the graphic approach is more convenient;

(c) The method is equally applicable for micro and macrodiamonds;

(d) The same simulation methodology is used to model the LC-curve during which slight changes to the size distribution might be introduced. If any changes to the size distribution seem necessary the entire process of size modelling is repeated from item (vi) in the modelling procedure until both the LP- and LC-curves are satisfactorily close to their respective sample curves.

(e) There must be an awareness of the fact that samples might have been treated differently in different sampling programs or may unwittingly come from different domains. Before data is combined individual subsample LP-plots must be examined to ensure that they represent the same size population in the deposit.

(f) A higher degree of variation in the size classes above 0.01 carats is observed in the graph in Figure 3-9. This is due to the low frequency of stones in these size classes. More samples of the same size from this domain will yield similar LP-graphs.

(g) Furthermore, if these samples are combined to form a larger diamond parcel, the variability in the large diamond size classes will be reduced. Higher variability may then occur in larger size classes further to the right on the graph. (This is illustrated in a case study section 4.2)

(h) Diamond size distribution modelling forms the backbone of diamond content estimation. Inappropriate modelling affects estimated diamond content and can eventually have serious consequences on average diamond value.

3.2.5 Diamond Concentration

Diamond content modelling is completed by incorporating diamond concentration with the diamond size distribution to obtain the LC-curve. A number of subsamples sufficient to allow compilation of a histogram of values are required to represent and model diamond concentration.

The key sampling requirement to ensure sample correctness is to find material that appropriately represents the deposit. While diamond size is represented by a minimum number of stones, diamond concentration is reflected by a minimum number of subsamples.

In section 3.1.3 the variable $N_w(A)$ is used to denote the number of diamonds that occur above weight w in domain A, which may be any fraction of the deposit under consideration. Subsample stone counts are observations of this variable, but for modelling are normalised to a common weight. Domain A in this case is thus defined by a fixed subsample weight. In the case of microdiamond sampling this weight is usually 8kg or 20kg.

Because of the large numbers of stones recovered during production it is possible to express diamond concentration as a continuous variable. The Gaussian transform function is most conveniently used to represent the statistical distribution for subsample concentration. Other distributions that have been used are the Lognormal, Weibull, Poisson and Negative Binomial.

Stones in the bottom size classes are eliminated by truncation. The statistical distribution of sample stone concentration is modelled on the basis of truncated sample stone counts normalised to a common sample weight.

The example shown in Table 3-1 is a combination of 63 subsamples. Average subsample weight is 8kg with normalised mean stone concentration of 35 stones per 8kg.

The sample histogram of stones/8kg is shown in Figure 3-10.

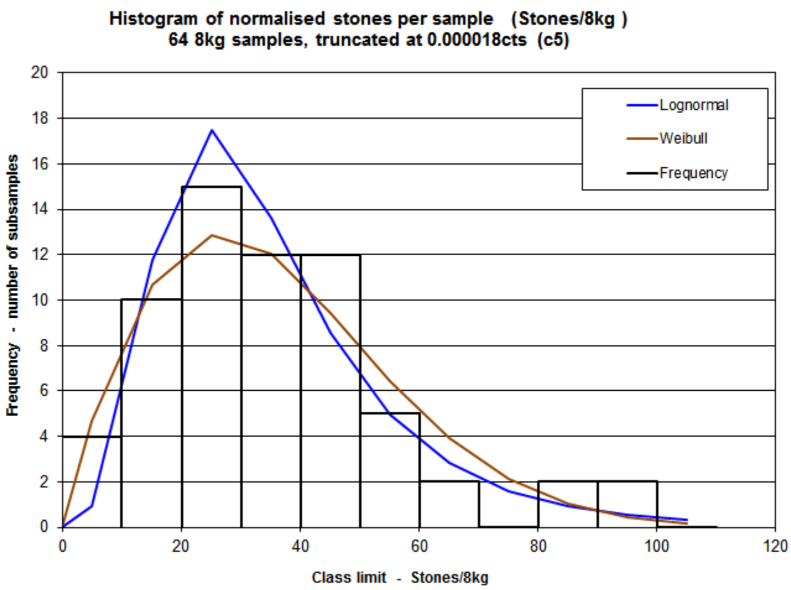


Figure 3-10: Histogram of sample stones/8kg with fitted Lognormal and Weibull distributions. Sample stone frequencies are truncated at size class C5 as indicated by diamond size modelling.

The best fitting lognormal and Weibull probability distributions overlay the histogram. Lognormal and Weibull mean and standard deviation are 35 and 19 respectively, with 35 and 6 for the Poisson. Either of these models could be used for diamond content modelling.

In cases where subsample weights vary more due to core loss or short sample intersection lengths, subsamples are resized on the basis of the Bayesian approach using a non-informative prior distribution. [15]

3.2.6 Incorporation of diamond concentration

Diamond concentration is incorporated by combining diamond size and diamond concentration in a single graph representing both variables to quantify diamond content. Size and concentration are combined by means of simulation in much the same way size distribution parameters are obtained.

For this purpose at least 1 million independent 8kg subsamples are simulated as follows:

(i) Each subsample is allocated a number of stones randomly drawn from the model obtained for truncated subsample concentration;

(j) Each stone is allocated a weight according to the stone size distribution model and allocated to a size class;

(k) Class frequencies for all the simulated subsamples are accumulated to form a typical diamond size and concentration assortment;

(l) LC-graphs are plotted for simulated sample and actual sample for comparison on one graph as shown in Figure 3-11.

(m) Modelling is complete when the graphs for simulated parcel and actual sample coincide.

(n) The simulated parcel contains diamonds in the modelled concentration with size distributed in accordance with the modelled size distribution.

(o) The LC-curve for the typical parcel represents the in situ distribution of diamond concentration with size and is expressed as a second degree polynomial.

(p) The LC-curve is used to calculate the number of stones and their combined weight per size class in the required size class configuration.

(q) If bottom cut-off alignment factors are available, the estimated recoverable diamond content is calculated.

(r) With the known tonnage of the simulated sample the resultant carat weight is used to express expected diamond grade in terms of carats/tonne or carats/100tonnes (cpt or cpht).

The curve for the example used in the illustration is given in Figure 3-11.

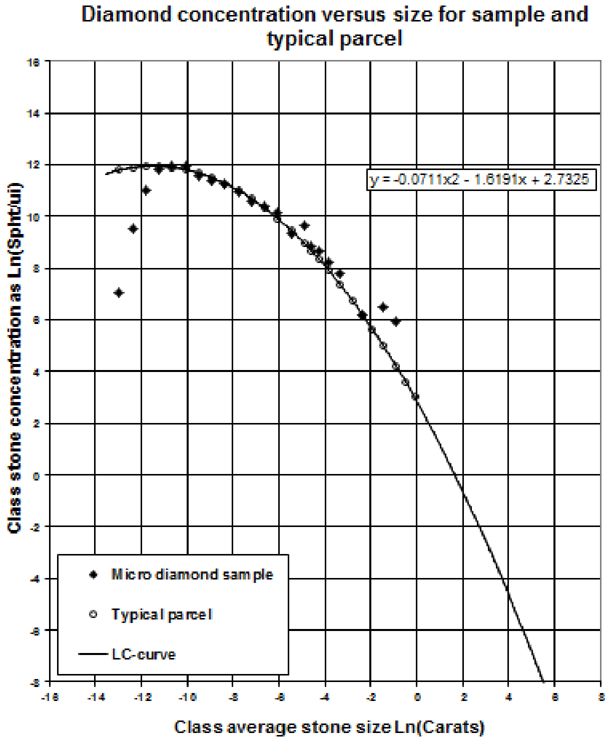


Figure 3-11: LC-curves for simulated typical parcel and sample. The shape of the curve relates to the distribution of diamond size. Its vertical location relates to diamond concentration.

The size distribution model comes under scrutiny again when diamond concentration is incorporated in the modelling procedure and may sometimes have to be adjusted if necessary. In the illustration there is no indication that any adjustment is required.

With enough stones available from sampling there is little doubt about the distribution of diamond size, but common sense wants to see points further along the X-axis in the larger diamond size classes for confirmation of the model.

In practice the model derived so far will be used to provide an estimate of diamond content with a caveat that it has to be confirmed with macrodiamonds from bulk sampling.

The curves for diamond size and diamond concentration shown in Figure 3-9 and Figure 3-11 would be regarded as reliable indicators of diamond content for the domain sampled.

3.2.7 Model confirmation

Without macrodiamonds the diamond size distribution model in the commercial size range is largely based on extrapolation. Confidence associated with diamond size and average diamond grade for the domain concerned are accordingly adversely affected. Confidence is gained only when the model is confirmed by the presence of macrodiamonds further along the size range. This is achieved by bulk sampling for macrodiamonds or by increasing the total size of the microdiamond sample substantially.

Macrodiamond recoveries from bulk sampling and microdiamond data from the same source listed in Table 3-1 are displayed on the same log probability grid in Figure 3-12.

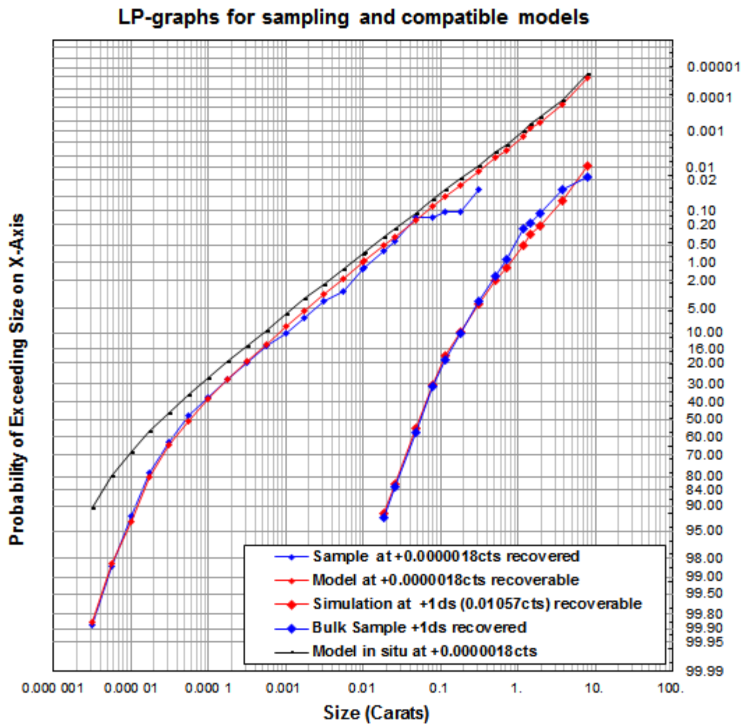


Figure 3-12: LP-model based on microdiamonds confirmed by macrodiamonds from bulk sampling. In situ model curve is shown, truncated at +0.075mm. Micro- and macrodiamond sample curves are accompanied by model curves adjusted for recovery losses at corresponding bottom cut-offs.

The graph shows the correspondence between the model and corresponding micro- and macrodiamond samples recoverable at +0.075mm and +1diamond sieve respectively. Both sample types deviate from the model in the top size classes due to higher variability in the less populated larger size classes.

In the next step macrodiamond concentration is incorporated into the modelling procedure by adding its LC-plot to the curve (Figure 3-11) so far obtained from microdiamonds. This is shown in Figure 3-13.

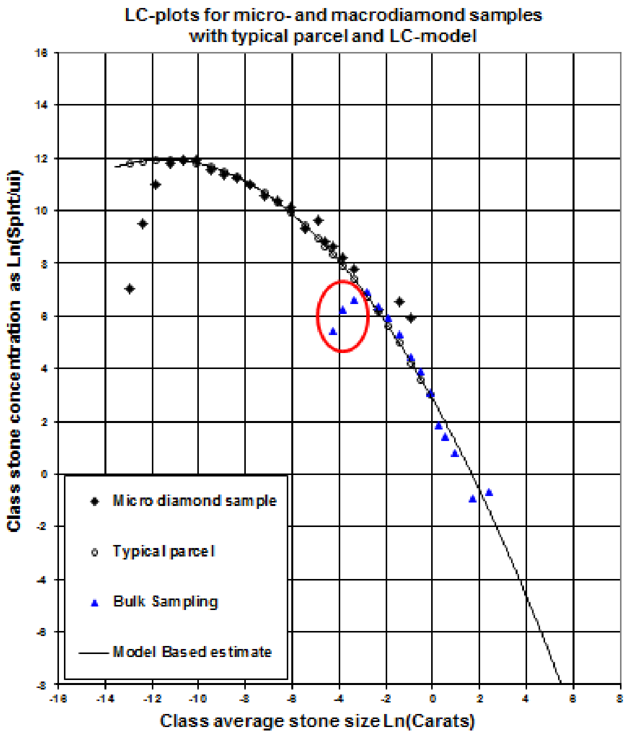


Figure 3-13: Macrodiamond sample incorporated in plots of diamond concentration versus diamond size, confirming size and concentration models derived from microdiamonds. Concentrations in three size classes affected by bottom cut-off (circled in red) are compared with model concentrations to obtain alignment factors.

Close correspondence between the micro- and macrodiamond sampling results on the one hand and the typical parcel on the other provides confidence in the diamond size and concentration models. The typical parcel is generated entirely on the basis of information derived from the microdiamond sample. The diamond size distribution and diamond concentration models used to simulate the typical parcel represent microdiamond sampling and is shown to conform to material obtained from a different sampling method, treated at a different facility and using a higher bottom cut-off aperture for diamond recovery.

Observed deviations of sample points from the typical parcel are attributed to higher variability due to low class frequencies or as a result of normal recovery losses and have no effect on the outcome of modelling. It demonstrates the robustness of the procedure and its nature of visual control.

The second degree polynomial is fitted to the typical parcel points and is used to calculate diamond concentration per size class in terms of stones/100tonnes per normalised class interval. Adjustment for class width and application of average stone size in each size class yields grade per size class in carats/100t. Summation of class grade above given bottom size class yields expected diamond grade for the domain.

A summary of sampling data and estimated diamond grade in size classes is shown in Table 3-4.

Table 3-4: Diamond grade from modelling, based on micro- and macrodiamond sampling results for the samples considered in the preceding illustrations from Table 3-1. Diamond grade at +5ds recovery is estimated at 154 cts/100t. Alignment factors are based on bulk sample recovery efficiencies.

Class number	Sieve class	Lower limit (cts)	Microdiamond stones From 520kg	Bulk sampling stones from 635 tonnes	Simulation of stones as in 800 tonnes	Model cts/tonne	+5ds alignment factor	+5ds cts/tonne
38	150+	149.8	0	0	0	0.0004	1	0.0004
37	100+	99.8	0	0	0	0.0008	1	0.0008
36	60+	59.8	0	0	0	0.0018	1	0.0018
35	45+	44.8	0	0	0	0.0016	1	0.0016
34	30+	29.8	0	0	0	0.0034	1	0.0034
33	20+	19.8	0	0	0	0.0053	1	0.0053
32	15+	14.8	0	0	1	0.0054	1	0.0054
31	+23	8.036	0	2	1	0.0173	1	0.0173
30	+21	3.691	0	2	7	0.0404	1	0.0404
29	+19	1.918	0	9	15	0.0591	1	0.0591
28	+17	1.423	0	8	15	0.0375	1	0.0375
27	+15	1.195	0	7	24	0.0255	1	0.0255
26	+13	0.703	0	75	87	0.0959	1	0.0959
25	+12	0.523	0	91	85	0.0670	1	0.0670
24	+11	0.317	1	272	267	0.1380	1	0.1380
23	+ 9	0.179	2	722	685	0.1980	1	0.1980
22	+ 7	0.117	0	989	962	0.1759	1	0.1759
21	+ 6	0.0792	1	1457	1481	0.1818	1	0.1818
20	+ 5	0.0485	0	3047	3293	0.2532	1	0.2532
19	+ 3	0.0256	8	3042	8237	0.3618	0.5	0.181
18	+ 2	0.0186	6	1043	7021	0.1890	0.2	0.038
17	+ 1	0.01057	17	841	19338	0.3384	0.05	0.017
16	C16	0.01000	2	0	2560	0.0329		1.544
15	C15	0.00562	46	0	35413	0.3347		
14	C14	0.00316	33	0	59237	0.3105		
13	C13	0.00178	76	0	92693	0.2751		
12	C12	0.00100	95	0	140446	0.2328		
11	C11	0.00056	116	0	201491	0.1881		
10	C10	0.00032	173	0	275609	0.1452		
9	C9	0.00018	226	0	361474	0.1070		
8	C8	0.00010	257	0	454822	0.0754		
7	C7	0.000056	309	0	544375	0.0507		
6	C6	0.000032	441	0	619554	0.0325		
5	C5	0.000018	501	0	674547	0.0200		
4	C4	0.000010	649	0	706629	0.0117		
3	C3	0.000006	587	0	703292	0.0065		
2	C2	0.0000032	405	0	664932	0.0035		
1	C1	0.0000018	345	0	603696	0.0018		
0	C0	0.0000010	89			0.0009		
							‘+5ds diamond grade	154 cts/100t

Estimated grade +1 diamond sieve, adjusted for recovery losses, is 154 cpht, compared with the bulk sample grade of 157 cpht.

Bottom cut-off alignment factors for bulk sample recovery are obtained by comparing bulk sample and model class concentration. The bottom three size macrodiamond classes are affected as shown in Figure 3-13. Bulk sample recovery in sieve classes +3, +2 and +1 are approximately 0.5, 0.2 and 0.05 of estimated in situ diamond content and accepted to serve as alignment factors for recovery in the bulk sample treatment plant.

If recovery in the anticipated production plant is similar, then these factors may be assumed for production. Metallurgical test work may lead to other factors, but until then the bulk sample factors are the best available.

Comparison of LC-plots for sampling and modelling and the closeness of bulk sample grade and model grade at comparable bottom cut-off confirm the validity of procedures.

3.2.8 Confidence limits

Confidence limits for diamond content estimates are obtained by means of simulation.

Under the assumption of a model for diamond size and concentration, different levels of sampling results are simulated and examined. Simulated results at the level of actual sampling are compared with 'known' diamond content to ascertain a level of uncertainty, which is then associated with the level of actual sampling. The level of sampling is measured in terms of the number of stones that are available and the number of subsamples that have been drawn.

Uncertainty with respect to diamond concentration decreases with an increase in the number of subsamples. More subsamples spread throughout the domain ensure a higher level of sample representation and smaller chance of having bias in observations of the variable. More stones available ensure a higher level of representation of the diamond size distribution.

Diamond concentration in kimberlite varies and the number of subsamples that is required to estimate diamond content varies accordingly. Simulation studies show that a domain with high diamond concentration requires less sampling to attain a certain level of confidence. If diamond concentration is high, it is easy to quickly obtain many stones to model diamond size, but a minimum number of subsamples are still required to ensure sample representation. If diamond concentration is low, a large number of subsamples are required to provide enough stones for size modelling. Alternatively the subsample support size must be increased.

This is illustrated by means of simulation as follows:

(i) Five levels of diamond concentration are assumed, varying from 4 to 72 stones per 20kg subsample.

(ii) Diamond size is assumed to be distributed in accordance with a distribution similar to the model obtained in Figure 3-12.

(iii) Sets of 100 samples are simulated, each sample containing a given number of subsamples. The first simulation begins with 20 subsamples per sample, the last contains 500.

(iv) From each set of 100 simulated samples the 10th and 90th percentile for sample concentration are recorded and plotted on a graph as shown in Figure 3-14. Similar graphs were produced in his PhD thesis by Thurston [59].

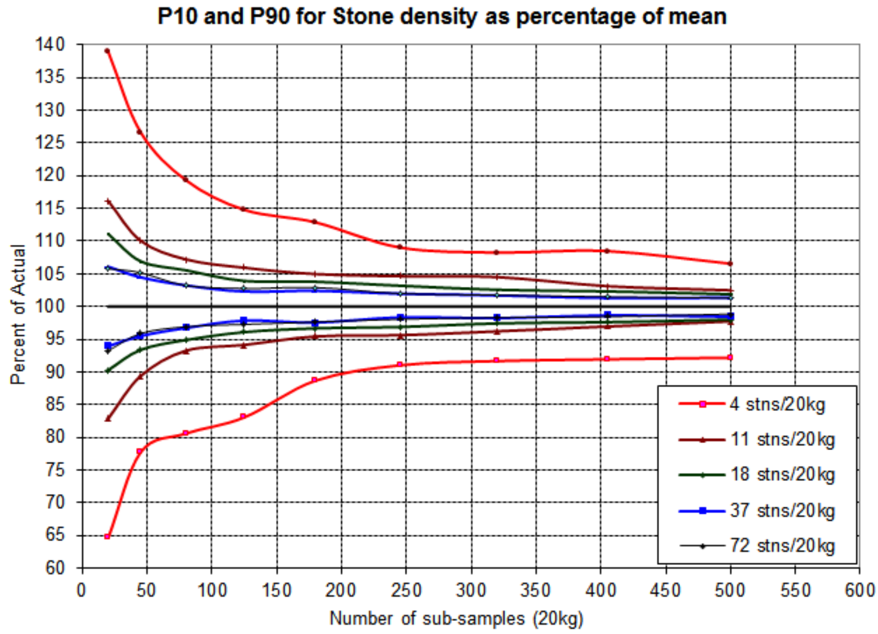


Figure 3-14 : Mean concentration with number of subsamples available for estimation. The graphs show dependence on domain concentration as well as number of subsamples. There is more uncertainty associated with sample diamond concentration when sampling from a low concentration domain.

For the domain in the example diamond concentration is 35 stones/8kg or 87 stones/20kg. The graph in Figure 3-14 shows that mean sample concentration from 64 subsamples will be within less than 5% of actual concentration 80% of the time. In the graph there is little difference between the probability limits for 37 and 72 stones/20kg.

The graphs show that uncertainty decreases slowly if diamond concentration is low. In order to be 80% sure of having mean sample concentration within 10% of the actual in a 4stones/20kg domain, at least 200 x 20kg subsamples must be drawn. If it is an 11 stones/20kg domain only 50 subsamples are required.

Any domain with size distribution similar to the distribution in Figure 3-12 and with diamond concentration of more than 18 stones/20kg will require only as few as 20 subsamples to reflect mean concentration within 10% of the actual, 80% of the time.

These levels of confidence assume that the samples are representative of the domain.

The results of the same simulation were used to examine uncertainty with respect to the distribution of diamond size. The five levels of diamond concentration and the numbers of subsamples per sample were used to calculate the number of stones available in each simulation. Log mean and log variance of stone size were calculated for each simulated sample and the 10th and 90th values recorded against the number of stones in the sample as shown in the graphs in Figure 3-15.

The graphs show that most of the variability in sample size distribution parameters occurs if fewer than 300 stones are available for modelling the distribution of diamond size. With more than 2000 stones in the combined sample it is clearly shown that most of the variability in distribution of diamond size is eliminated.

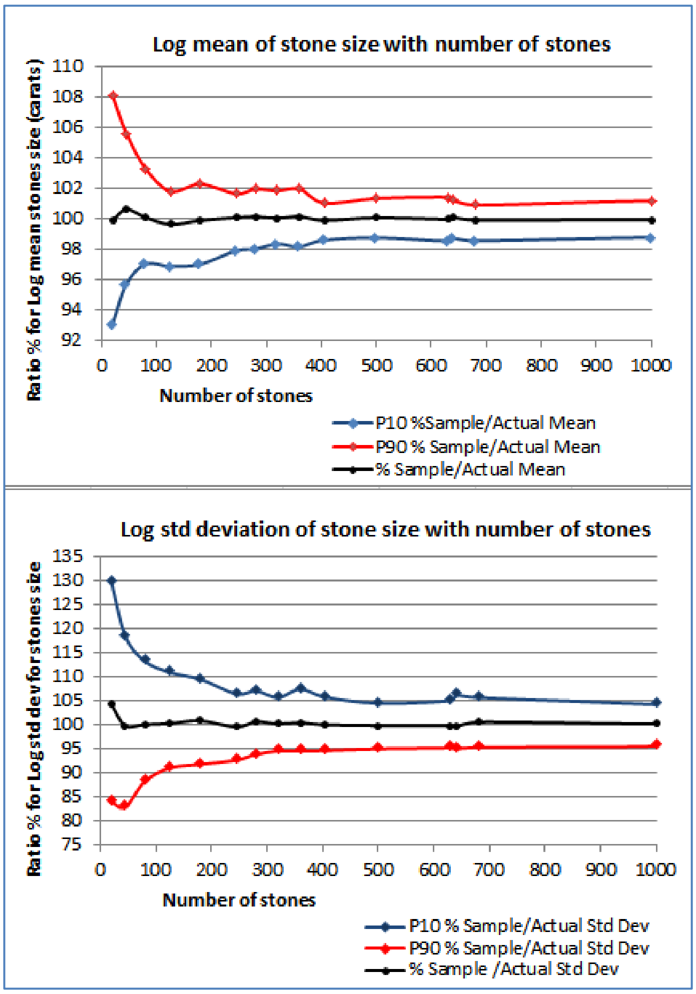


Figure 3-15 : Stone size mean and standard deviation with number of stones available for estimation. Log mean and variance of the distribution of stone size in samples containing given stone numbers are calculated and the 10th and 90th percentiles from 100 samples plotted as shown. Calculated sample values are expressed as % of known actual. Most variability occurs when a sample comprises of less than 300 stones. Thereafter variability decreases slowly.

Confidence limits are finally calculated by assuming that the log mean and variance for diamond size could lie within 1% and 4% from the actual values for the domain, with sample diamond concentration varying within 4% of the actual. This is carried out using the 'extreme' parameters to generate LC-curves and calculating associated diamond grade. A summary of parameters obtained this way is given in Table 3-5.

Table 3-5 : Model, with possible lower and upper confidence limit parameters

	Model	Lower	Upper
Log mean	-11.45	-11.56	-11.34
Log standard dev	2.68	2.57	2.79
Stones/8kg	33	35	37
Grade (cpht)	154	75	285

Resulting LC-plots are shown in Figure 3-16 with truncated microdiamond and bulk sampling results.

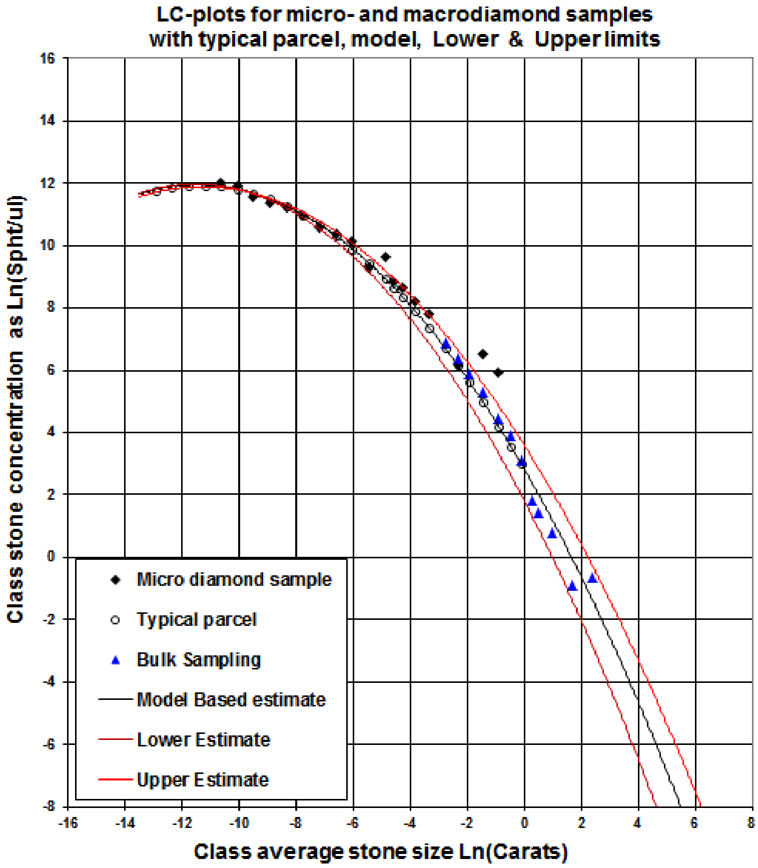


Figure 3-16 : LC-plots for samples and model with distributions for possible lower and upper size distributions representing lower and upper grade potential amounting to 75cpht and 280cpht, with modelled grade of 154cpht.

3.2.9 Comments

Diamond content is determined by domain. If a domain is so large that there is a chance that there may be changes in the distribution of diamond size within the large domain, then the domain must be broken up into subdomains, each having its own unique size distribution. This may be likely in the case of a domain extending over a large area or with depth.

Geological modelling subdivides the deposit into geologically homogenous domains. Diamond content estimation is carried out by domain and by imposing a block model onto the geological model a resource block model is obtained. If sufficient sampling data is available diamond content is estimated locally in resource blocks by means of spatial statistical procedures.

The following mistakes are still being made in the industry due to a lack of understanding of basic sampling principles:

- Too few holes are drilled into a pipe <u>initially</u>;
- Core is collected, combined then split into 'aliquots', without recording aliquot location;
- Core is visually sampled and kimberlite material is selected with a bias toward better looking material, with no regard to contamination;
- A bulk sample from single location in a domain is compared with multiple microdiamond subsamples from various locations in the domain, expecting coherence.

Of the two components of diamond content, namely size distribution and concentration, the latter is more likely to be biased due to bad sampling practice. Many stones from a few subsamples may lead to a reasonable size distribution model, but the number of subsamples might not be representative of the domain and the associated diamond concentration could be biased.

It is common that sampled macrodiamonds may be spatially more restricted than sampled microdiamonds as they often come from a single bulk sample from near surface, while microdiamonds may be derived from treatment of drill core from depth. In such cases there may be discrepancy between grades derived from microdiamonds and the observed or derived grade from macros. The grades to be used are those corresponding to the most representative sampling program.

All modelling is based on sampling information. If this does not reflect the source to be mined, then the most sophisticated estimation techniques will not provide any confidence in estimates.

At the end of the modelling procedure the image seen in Figure 3-13 provides high confidence in the entire assessment procedure, but this is not always the case.

When a domain has been sampled by means of more than one sampling method the modelling procedure will expose sampling or treatment issues affecting diamond size and diamond concentration. Correct micro- and macrodiamond sampling is expected to lead to similar diamond content estimates. Incorrect sampling could affect either diamond size or diamond concentration or both. For instance, if micro- and macrodiamond sampling results come from the same domain in the deposit, the sample LC-curves must suggest the same simulated typical parcel. If the typical parcel deviates systematically from sample points it means the typical parcel was generated with either incorrect diamond size distribution or incorrect diamond concentration, or both.

If micro- and macrodiamond recoveries do not come from the same excavated material there may be differences in diamond content between the two sets of samples. If the two sets of samples are coherent they will indicate identical models and diamond content.

If the size distributions are not similar, the samples could be representing different domains, which must checked before any further progress can be made.

Non-coherence with respect to size is observed during size distribution modelling. This could imply recovery problems or misinterpretation of geological logs, resulting in an attempt to assimilate two different kimberlite families with different size distributions [20].

Differences in diamond concentration between microdiamond and macrodiamond sampling results can only be observed by inspection of sample LC-graphs. Non-coherence is exposed when the LC-graphs for the two sets of samples are parallel but shifted with respect to one another as demonstrated in Figure 3-17.

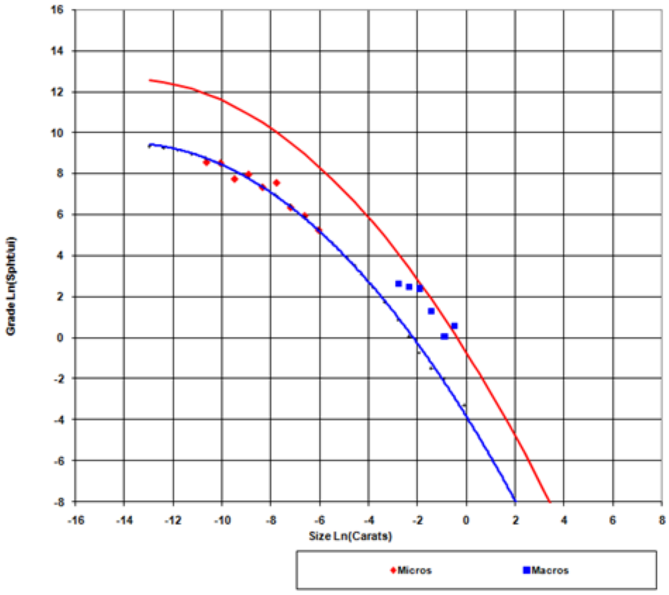


Figure 3-17 : Non-coherence with respect to diamond concentration.

Non-coherent sampling results occur often when sampling is in early sampling phases and where sampling data may still be biased. If under such circumstances a LC-curve is adjusted to 'best fit' the two sets of points, disregarding the size distribution suggested by sampling data, the resulting model will have a distorted size distribution, with serious implications on diamond content and revenue estimates.

This is still happening in the Industry.

3.2.10 Alternative modelling procedure

An alternative modelling procedure has been developed for De Beers [37]. The objective in the procedure is to estimate the parameters of a lognormal distribution, starting from several sets of data with different, known levels of truncation. The approach is Bayesian and values are assigned to both parameters, generated from a non-informative prior distribution. This is followed by an iterative procedure.

At each step:

(i) All missing stone weights are generated, given the current parametric values and the number of present, truncated stones;

(ii) New values are generated for the parameters using the augmented data.

The final result of the procedure is an estimate of both parameters as well as confidence limits.

3.2.11 Extreme Value Statistics

Extreme value statistics was considered at the early stages of the research. Work done by Caers, Rombouts and Vynckiers is focussed on the application of extreme value distributions to diamond size and diamond value [6]. Diamonds are not considered in size classes and their work does not involve transition from in situ to recoverable diamond content. However, this is not important insofar as they are only concerned with the tail of the diamond size distribution.

PART II CASE STUDIES

4 Case Studies I

Résumé

L'échantillonnage d'un gisement kimberlitique se fait par étapes, ce qui permet de mieux gérer les travaux à effectuer pour évaluer son intérêt économique.

Peu de gisements sont économiquement rentables. Ils doivent être identifiés de façon précoce et certaine. Un échantillonnage par étapes évite toute dépense inutile. Les différentes étapes peuvent varier en fonction du mode d'excavation ou de traitement des échantillons, mais elles visent toutes au même objectif qui est d'ajouter de la connaissance au gisement.

Deux cas d'étude sont présentés dans ce chapitre.

Le premier cas d'étude porte sur un gisement de concentration faible mais erratique, qui a été échantillonné en deux étapes pour en récupérer les microdiamants. La faible concentration en pierres impose des échantillons de grande taille. Sa forte variabilité requiert aussi des options d'échantillonnage appropriées. En telle situation, le recours aux microéchantillons s'avère utile.

Le second cas d'étude porte sur un gisement de forte concentration. Il est aussi échantillonné en deux étapes, la première pour les microdiamants, la deuxième pour les macrodiamants. La forte concentration en microdiamants est une situation idéale pour recourir aux microéchantillons, comme en témoigne la précision des estimateurs obtenus à l'aide d'eux seuls.

Overview

Sampling is done in phases in order to manage the potential magnitude of work that may be encountered in the economic evaluation of a kimberlite body.

Few deposits are economically viable and this must be identified early and confidently. Phased sampling prevents unnecessary high expenditure. Sampling phases may differ with respect to sample excavation and treatment, but the underlying aim is to add value each time.

Two case studies are presented.

The first study is based on a low diamond concentration body which was sampled for microdiamond recovery in two phases. The study illustrates the high degree of variability associated with low concentration kimberlites and the need to select appropriate sampling options. It also demonstrates

the need for large sample support when diamond concentration is low, and shows that there is a place for microdiamond sampling even under such conditions.

The second case study involves a high concentration kimberlite, also assessed on the basis of two sampling phases, Phase I for microdiamond recovery and Phase II for macrodiamonds from bulk sampling. The relatively high proportion of small stones in the deposit leads to moderately high concentration of microdiamonds, which is an ideal case for microdiamond sampling and estimation as seen in the accuracy of initial estimates based on microdiamonds only.

4.1 Case study 1

4.1.1 Project background

The author was not involved in the design of the Phase I sampling program. Recommendations with respect to Phase II sampling were not followed and the consequences are mentioned at the end of the case study.

Immediately after discovery of this kimberlite a Phase I sampling program was launched to collect material for diamond content assessment. Diamond drilling and surface sampling yielded 233 microdiamonds from 840kg of kimberlite material treated by means of Caustic Fusion. Sampling was aimed at an initial assessment of the importance of the body on the basis of its diamond content.

Phase II sampling commenced as soon as the results of Phase I sampling indicated that the deposit might have economic potential. Microdiamond sampling yielded an additional 610 stones from 3.76 tonnes of sampling material treated by means of Caustic Fusion.

4.1.2 Phase I Sampling and Estimation

4.1.2.1 Data

A sample was collected in the form of 4 groups of subsamples with average subsample weight of 8kg. Initial results indicated one kimberlite family.

Material was collected from the surface of the pipe and from drill core.

The two sets of subsamples from surface were collected from bulk material collected at specific locations on the surface of the pipe. Two other sets of subsamples were collected from drill core, each set from a drill-hole in consecutive 2m core sections.

Subsamples were individually packed and the two groups of subsamples were sent to the laboratory as one consignment. Recovery took place above 0.106mm square mesh.

Table 4-1 is a summary of caustic fusion results per subsample.

Table 4-1 : Subsample weight and stone count.

	SUBSAMPLE GROUP							
	Surface 1		Surface 2		Core 1		Core 2	
Subsample	Weight kg	Stones	Weight kg	stones	Weight kg	stones	Weight kg	stones
1	8.0	2	8.0	0	8.0	2	8.0	0
2	8.0	1	8.0	1	8.0	0	8.0	0
3	8.0	0	8.0	1	8.0	5	8.0	1
4	8.0	0	8.0	1	8.0	1	8.0	0
5	8.0	2	8.0	0	8.0	0	8.0	3
6	8.0	1	8.0	2	8.0	2	8.0	0
7	8.0	2	8.0	4	8.0	0	8.0	0
8	8.0	3	8.0	6	8.0	1	8.0	2
9	8.0	0	8.0	4	8.0	1	8.0	0
10	8.0	9	8.0	2	8.0	0	8.0	2
11	8.0	3	8.0	1	8.0	0	8.0	4
12	8.0	1	8.0	3	8.0	2	8.0	1
13	8.0	4	8.0	3	8.0	1	8.0	0
14	8.0	1	8.0	0	8.0	2	8.0	0
15	8.0	1	8.0	1	8.0	0	8.0	0
16	8.0	0	8.0	3	8.0	2	8.0	0
17	8.0	3	8.0	1	8.0	1	8.0	0
18	8.0	6	8.0	4	8.5	1	8.0	0
19	8.0	4	8.0	**24**	8.5	0	8.0	0

20	8.0	**49**	8.0	9	8.5	0	8.0	0
21	8.0	5	8.0	2	8.5	0	8.0	0
22	8.0	1	8.0	2	8.5	0	8.3	0
23	8.0	0	8.0	3	8.5	0	8.3	1
24	8.0	1	8.0	1			8.3	0
25	1.9	0	8.0	3			8.3	0
26			8.0	4				
27			8.0	1				
28			8.0	2				
29			8.0	2				
30			8.7	1				
31			8.8	4				
32			8.6	4				
Total kg 840	193.9		258.1		187.0		201.0	
Total stones 233		99		99		21		14

Two of the subsamples from surface yielded significantly more stones, resulting in higher average stone concentrations for the corresponding subsample groups.

Table 4-2 is a summary of the data showing the size breakdown for each group of subsamples, including basic sampling statistics.

Table 4-2 : Size breakdown and subsample statistics

Size class (mm)	Microdiamonds				Total
	Surface 1	Surface 2	Core 1	Core 2	
+3.350	0	0	0	1	1
+2.360	1	0	0	0	1
+1.700	0	0	0	0	0
+1.180	1	1	0	0	2
+ .850	1	0	0	0	1
+ .600	1	0	0	0	1
+ .425	0	1	0	0	1
+ .300	6	2	2	1	11
+ .212	12	15	0	1	28
+ .150	21	37	5	3	66
+ .106	56	43	14	8	121
Total stones	99	99	21	14	233
Total carats	0.2196	0.0373	0.0014	1.1526	1.4109
Sample weight (kg)	194	258	187	201	840
Number of subsamples	25	32	23	25	105
Average kg/stone	1.96	2.61	8.90	14.36	3.60
Average Stones/8kg	4.1	3.1	0.9	0.6	2.2
Average carats/tonne	1.13	0.14	0.01	5.73	1.68
Average stone size (carats)	0.0022	0.0004	0.0001	0.0823	0.0061

Upon inspection of the data the following points are noted:

- In spite of low stone counts, some larger microdiamonds occurred.
- Surface 1 contained one subsample with a stone count of 49.
- Surface 2 contained one subsample with a stone count of 24.
- Removing outliers from the surface subsamples decreases average stone counts per 8kg sample from 3.1 to 2.4 and from 4.1 to 2.2 respectively.
- Stones above 0.85mm occur in both surface and core subsamples.
- The total number of stones above 0.106mm, excluding the two outlier subsamples, amounts to 160.

- Combined core subsamples show lower stone counts even after exclusion of surface outliers.
- Sample stone count per 8kg is low and implies that economic potential will have to rely on the coarseness and quality of the in situ diamonds.
- It is obvious that a large amount of material will have to be treated to acquire enough stones for size analysis.
- In this case, where microdiamond occurrence is low with a potentially coarse diamond size distribution, the use of macrodiamond sampling and conventional (DMS) sample treatment could be preferred during early sampling phases.
- Whether this is a single domain kimberlite will have to be tested if and when additional sampling information becomes available. For this purpose similar subsamples will be required with their locations recorded.

Log-probability plots for the four groups of subsamples in Figure 4-1 show a wide dispersion of size curves, but this is mainly due to the low numbers of stones present in the data.

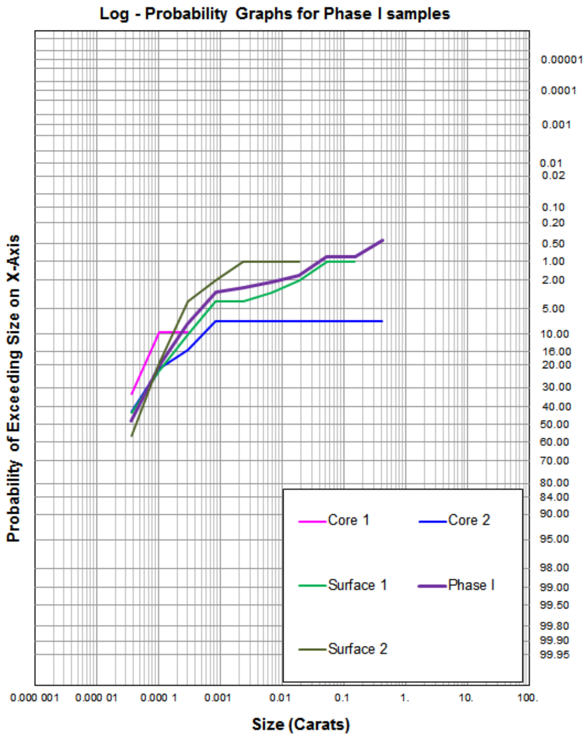


Figure 4-1 : Size distribution plots for Phase I subsample groups

In view of the small number of stones available it is not possible to come to a meaningful conclusion with respect to any differences in size distribution between core and surface samples.

4.1.2.2 Diamond size distribution

Figure 4-2 shows the log probability distribution of diamond size, depicting all 233 stones in the combined Phase I sample, including the two outlier subsamples. Individual subsample results are not plotted due to stone sparseness.

The sample LP-curve is heavily influenced by the presence of larger microdiamonds and subjective judgement was used to obtain parameters for a two-parameter lognormal distribution to fit the data. A lognormal distribution with mean 0.0000049 and variance 0.15 was fitted to the data.

The resulting plots are shown in Figure 4-2.

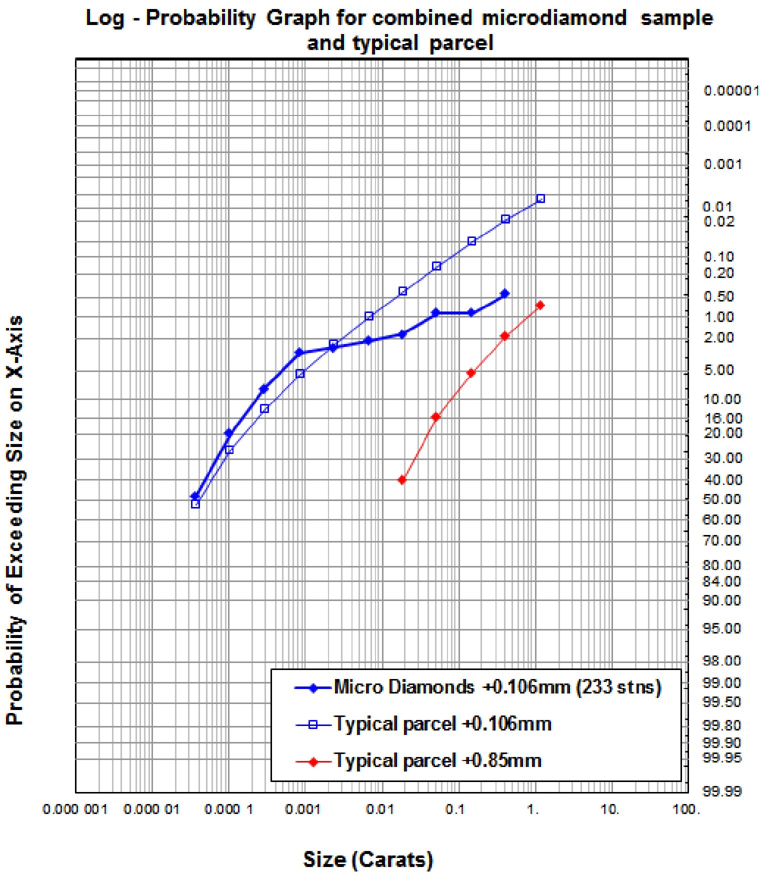


Figure 4-2 : Sample and Model Log-Probability graphs. Sampling data is shown at bottom truncation of 0.106mm.

Model and sample plots truncated at +0.106mm are shown on the left, with the model truncated at +0.85mm shown on the right. The model does not fit the sampling data particularly well, and a simulation exercise was carried out to examine sample variability.

Three diamond parcels were simulated and their LP-graphs plotted as shown in Figure 4-3. The parcels were composed of diamonds from 840kg simulated samples, assuming average diamond concentration of 22 stones/80kg and the modelled stone size distribution.

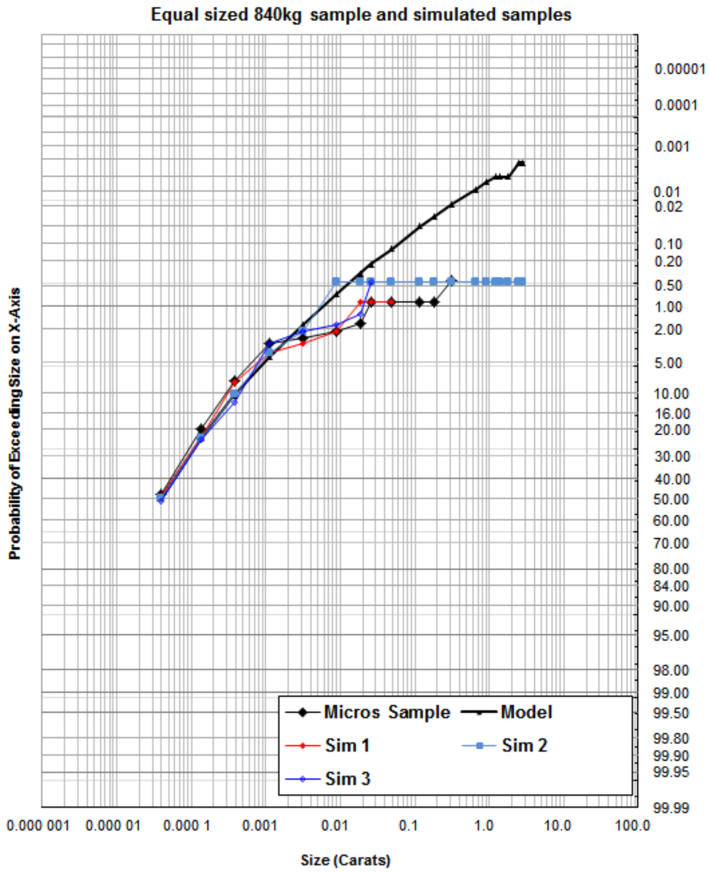


Figure 4-3 : Simulated and sampled size distributions, all truncated at 0.106mm. LP-curves are shown for typical parcel, 840kg sample and three (typical) diamond parcels from simulated 840kg samples.

The model curve is shown with the sample and three simulated parcel curves.

Similarity between simulated samples and actual sample is obvious and shows that the deviation of the model from the actual sample in Figure 4-2 is most likely due to low diamond counts. (Sampled and simulated stone frequencies are shown further down in Table 4-3.)

4.1.2.3 Diamond content

Diamond content modelling was completed by creating a typical parcel with size distribution according to the selected model and with mean diamond concentration equal to 22 stones per 80kg, as observed in sampling results.

The distribution is shown in the form of a LC-plot of the sampling results with typical parcel as shown in Figure 4-4.

From experience with other bodies the two outlier subsamples were not excluded from the analysis. Although the two samples were recognised as ‘outliers’, experience has shown that that exclusion of outlier subsamples could reduce diamond content materially.[19]

In this case average diamond concentration would be reduced from 22 to 16 stones/80kg.

[19] Ferreira JJ, Estimation of diamond content for the Grib kimberlite, Archangelsk, 2011.

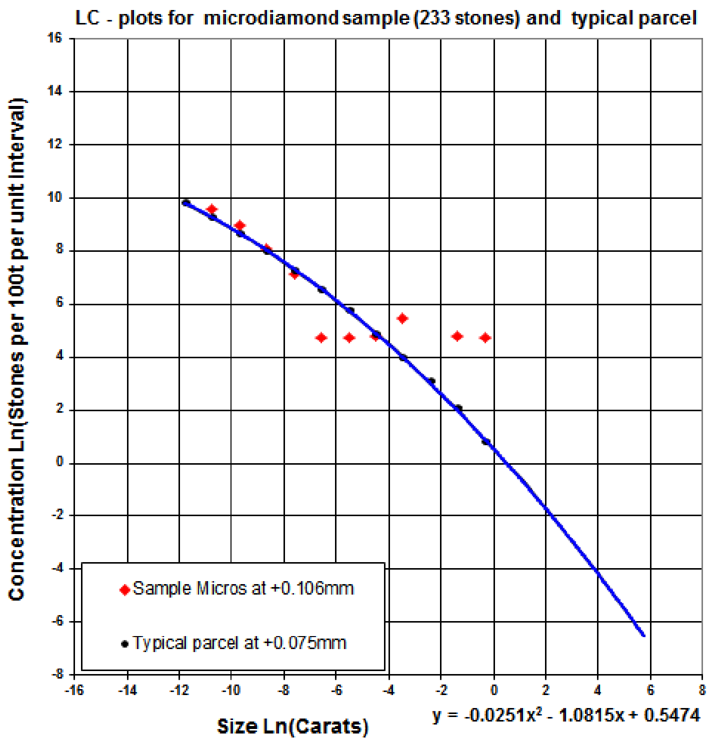


Figure 4-4 : Distribution of diamond concentration, derived from 840kg microdiamond sample containing 233 stones. The LC-curve is derived from a simulated size assortment of diamonds based on the size distribution model and diamond concentration at 22 stones/80kg.

The LC-curve with corresponding plot of microdiamond size class values is shown in Figure 4 4, with concentration depicted in terms of stones per 100tonnes per unit interval versus diamond size in carats.

As before, the model does not seem to fit the data well, except for the four sample points to the left in the picture. Most of the deviation between model and actual data occurs in the larger size classes on the right where stones occur more sparsely.

Modelling suggests diamond grade of approximately 15 carats/100tonnes (cpht) at +5 diamond sieve (+1.47mm) recovery, but with low confidence.

The diamond size and concentration model parameters used to assess diamond content were regarded unsatisfactory and more sampling was thought to be required for recovery of a larger diamond parcel. The best option would be bulk sampling for the recovery of macrodiamonds.

As bad as it may seem the model was nevertheless used to simulate larger diamond parcels to give indication of the numbers of macrodiamonds that may be expected from future bulk sampling. Results are listed in Table 4-3, showing stone frequencies for diamonds from the three 840kg simulated samples and for increased sample sizes of 8, 24 and 96 tonnes.

Table 4-3 : Sampled and Simulated stones per size class. Results in this table give an indication of the size of bulk sample that would be required to achieve meaningful numbers of stones above +5 diamond sieve, given the size distribution model in Figure 4-2 and average diamond concentration of 22 stones/80kg.

Diamond size class	Numbers of diamonds recovered from sampling and obtained by simulation						
	Sampling	Sim1	Sim2	Sim3	Sim6	Sim7	Sim8
	840kg	840kg	840kg	840kg	8000kg	24000kg	96000kg
5ct							
4ct							
3ct			1			1	1
10gr							
8gr					1	1	1
6gr							
5gr							
4gr							
3gr							2
+11	1						
+9	1						4
+7					1	2	6
+5		2			4	6	26
+3				1	5	13	38
1.18	2			2		5	20
0.85	1	3		1	6	24	97
0.60	1	2	4	1	16	68	288
0.425	1	2	4	2	49	164	693
0.300	11	9	15	21	132	373	1,559
0.212	28	34	29	26	313	847	3,445
0.150	66	60	62	63	567	1,742	6,857
0.106	121	118	115	113	1,106	3,354	13,363
Totals:	233	230	230	230	2,198	6,600	26,400
All samples were generated on the basis of modeled diamond size distribution and concentration.							

The table shows that approximately 195 stones above 0.85mm will be recovered from a 96 tonne bulk sample.

4.1.2.4 Result

The diamond content model suggests a deposit grade of approximately 15 carats/100tonnes (cpht) at +5 diamond sieve (+1.47mm) recovery.

The estimate is entirely dependent on the assumption of a diamond concentration of 22 stones/80kg above 0.106mm and the diamond size distribution represented by the probability model in Figure 4-2.

Phase I sampling results strongly suggests a next sampling phase (Phase II) to obtain confidence in diamond size and concentration models.

In view of the high level of uncertainty and the certainty of a Phase II sampling program no attempt was made to calculate confidence limits for Phase I grade estimates.

It was recommended that a 1000 tonne bulk sample be excavated to recover an estimated 2000 stones above 0.85mm. This would be suitable for confirmation of the microdiamond size distribution model and to give a first impression of the quality of macrodiamonds to be expected from the deposit.

Alternatively it was recommended that core drilling should be extended to collect microdiamond samples. It was recommended that this should take place in phases to prevent over-sampling. The purpose was to confirm the diamond size distribution and concentration and to provide more information for the development of a geological model for the deposit.

4.1.3 Phase II Sampling and Estimation

4.1.3.1 Data

The total sample weight was increased from 840kg to 4.606 tonnes, which yielded an additional 610 diamonds above +0.106mm. Stone counts were recorded above 0.106 mm and diamond recovery was reported in mm sieves from 0.106mm to 4.75mm as before.

The sample comprises 474 subsamples from 8 drill holes at an average weight of 7.9kg per subsample. Average stone concentration is 13 stones per 80kg, compared with 22 stones per 80kg in Phase I.

The data is summarised in Table 4-4 in the form of a size breakdown per drill hole with a summary of sample statistics.

Table 4-4: Phase II Microdiamond sampling data

Hole number	1	2	3	4	5	6	7	8	Total Phase II
Sample Weight kg	1083	973	322	335	484	71	118	380	3766
Diamonds	171	157	70	33	60	8	32	79	610
Subsamples	138	122	40	42	61	9	15	47	474
4.750 mm	0	0	0	0	0	0	0	0	0
3.350 mm	0	0	0	0	0	0	0	0	0
2.360 mm	0	0	0	0	0	0	0	0	0
1.700 mm	0	0	0	0	0	0	0	0	0
1.180 mm	4	1	0	0	0	0	0	0	5
0.850 mm	2	3	0	0	0	0	1	1	7
0.600 mm	0	5	1	2	1	0	1	1	11
0.425 mm	5	6	1	0	4	0	1	2	19
0.300 mm	7	11	8	4	7	2	3	7	49
0.212 mm	25	13	8	3	8	0	5	7	69
0.150 mm	45	45	14	8	14	1	6	17	150
0.106 mm	83	73	38	16	26	5	15	44	300
0.075 mm	0	0	0	0	0	0	0	0	0
Stones/80kg	12.6	12.9	17.4	7.9	9.9	9.0	21.7	16.6	13.0
Average Subsample weight kg	7.8	8.0	8.1	8.0	7.9	7.9	7.9	8.1	7.9

Subsamples consisted of approximately 2.4 metres of consecutive lengths of core from each drill hole.

Inspection of the individual subsamples reveals that the kimberlite seems to contain diamonds almost uniformly distributed in low concentration. With the exception of a few isolated subsamples with high stone counts, sampling consistently yielded low stone counts. Drill holes reportedly intersect a single geological domain and with data giving evidence of the same, it was accepted that the data comes from a single domain.

Subsample stone frequencies were normalised to a common weight of 8kg. In view of the uniformity of subsample weights, subsample concentration was factorised with the ratio $(8/Subsample\ weight)$ to normalise diamond concentration.

A histogram of normalised stone concentration is shown in Figure 4-5.

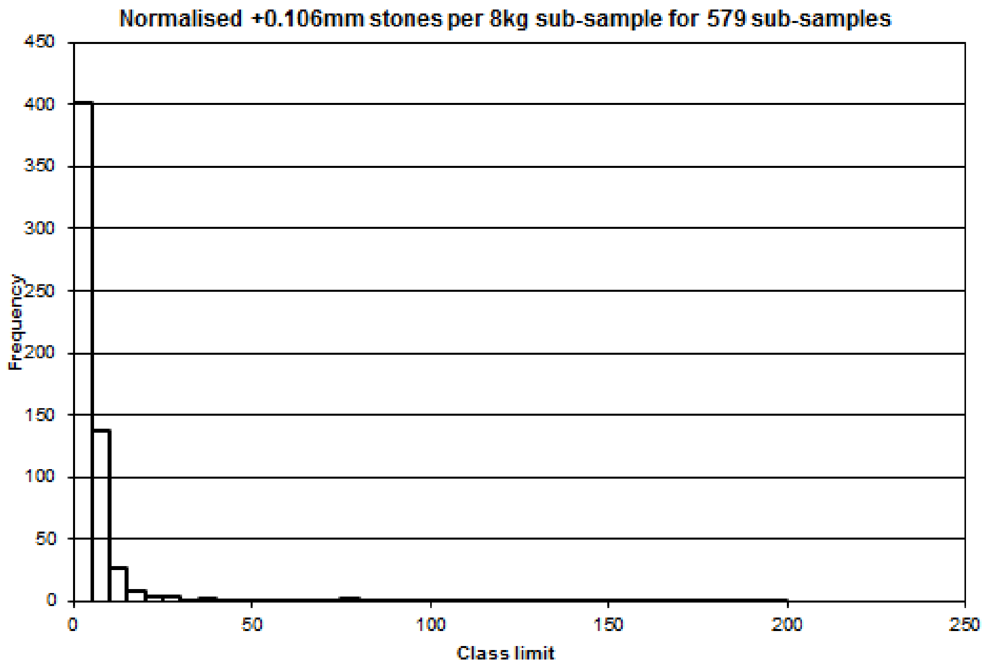


Figure 4-5 : Histogram of subsample stone concentration in stones/8kg above 0.106mm

The graph shows that the majority of subsample stone counts fall below 5 stones/8kg, with frequencies occurring up to 49 stones/8kg.

A substantial amount of material was treated for diamond recovery, which is essential in the case of a deposit with such low diamond concentration. However, whether so much additional microdiamond sampling was necessary remained to be seen.

4.1.3.2 Diamond size distribution

LP-graphs for combined subsamples per hole were plotted and are shown in Figure 4-6.

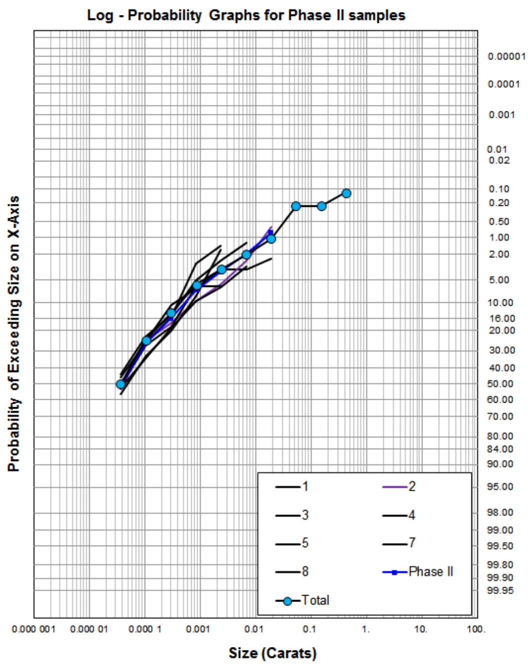


Figure 4-6 : Phase II subsamples combined by drill hole.

The distribution seems significantly more regular compared with what was seen in Phase I. Size modelling by means of simulation yields a lognormal model with mean and variance equal to 0.00000494 and 0.153, as before. (Phase II data was not seen when Phase I modelling was done…)

A typical parcel was simulated and its LP-graph is shown with the actual sample in Figure 4-7.

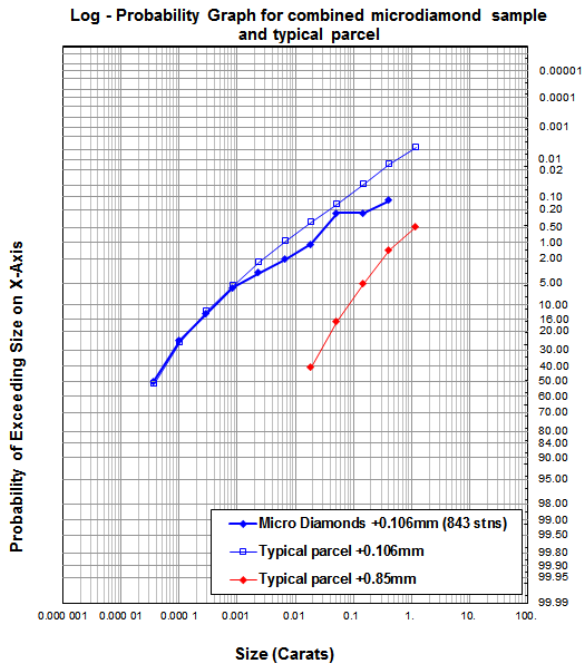


Figure 4-7 : LP-graph for combined Phase I and II microdiamond samples with typical parcel, both truncated at 0.106mm. Typical parcel truncated at +0.85mm is shown on the right.

The graphs indicate that sampling recovered more stones in the upper size categories compared with the typical parcel. This does not mean that the model parameters are conservative as the deviation is caused by a very small number of stones in these size classes.

The behaviour of the size distribution model was tested by simulating 50 samples of size similar to the actual sample and plotted with the combined sample in Figure 4-8.

Higher variability is demonstrated in the larger size classes. Although the actual sample seems to contain more stones in the large size classes, removal of two stones from the sample places the sample graph within the limits set by the 50 simulated samples.

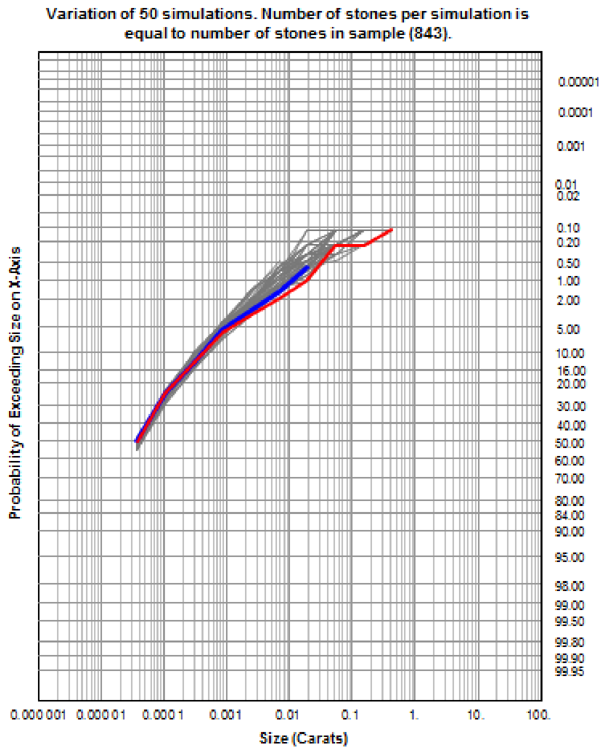


Figure 4-8 : Red curve shows actual sample with 50 simulated samples of same size. The simulated samples show higher variability in the larger size classes. Blue curve represents sample without two stones in the largest size classes.

The accepted model suggests a slightly more conservative rather than optimistic diamond size distribution.

4.1.3.3 Diamond grade

Microdiamond samples were simulated by generating 8kg subsamples assuming diamond potential to be a Poisson variable with lambda equal to 1.3 (stones/8kg) and with diamond size drawn from a two parameter lognormal distribution with mean and variance equal to 0.00000494 and 0.153 as shown in Figure 4-7.

For comparison a 400 ton typical microdiamond sample was generated and the LC-curve of the resulting diamond parcel is shown with the actual 4.6 tonne microdiamond sample points in Figure 4-9.

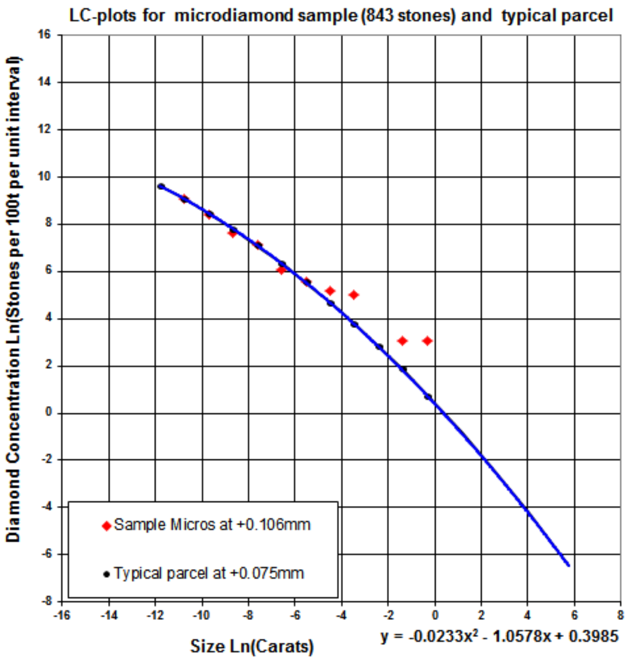


Figure 4-9 : Distribution of diamond concentration for combined sample and typical parcel. Typical parcel comprises simulated diamonds in 400 tonnes of kimberlite with diamond content as per size distribution model and average diamond concentration of 13 stones per 80kg of sample.

The distribution of diamond concentration takes the form of a second degree polynomial and was used to populate diamond size classes in accordance with diamond size and diamond concentration characteristics as reflected by the 4.6t sample from the deposit. If sampling is representative then the typical parcel represents deposit diamond content.

No subsample was eliminated from this simulation, neither because of having high stone count nor by being barren.

4.1.3.4 Result

Diamond grade was estimated at 13cpht and 12cpht at +0.85mm and +1.18mm recovery. This is in line with the results obtained in the Phase I assessment.

The appearance of the sample LP- and LC-curves suggests the potential of higher grade, but at this stage it can only be confirmed by bulk sampling and the recovery of macrodiamonds, which will happen when sampling is motivated by the need to assess diamond value.

4.1.4 Sampling assessment

The close correspondence between grade estimates based on the 840kg Phase I sample and the expanded 4.60t Phase II sample questions the feasibility of the size of the expanded sample.

Optimality of sampling is assessed in view of the magnitude of the sampling campaign so far and the amount of uncertainty still remaining. The nature of the sampling data provides the opportunity to examine both the ideal subsample support size and the number of subsamples.

4.1.4.1 Subsample support size

Subsamples were composed of approximately 2.4m sections of core, selected continuously down each drill hole and treated separately. The way the subsamples were taken makes it possible to combine multiples of 8kg units to form larger natural subsamples to a maximum support size of 48kg. Histograms for diamond concentration expressed as stones/100kg for subsample sizes, increasing from 8kg to 48kg are shown in Figure 4-10.

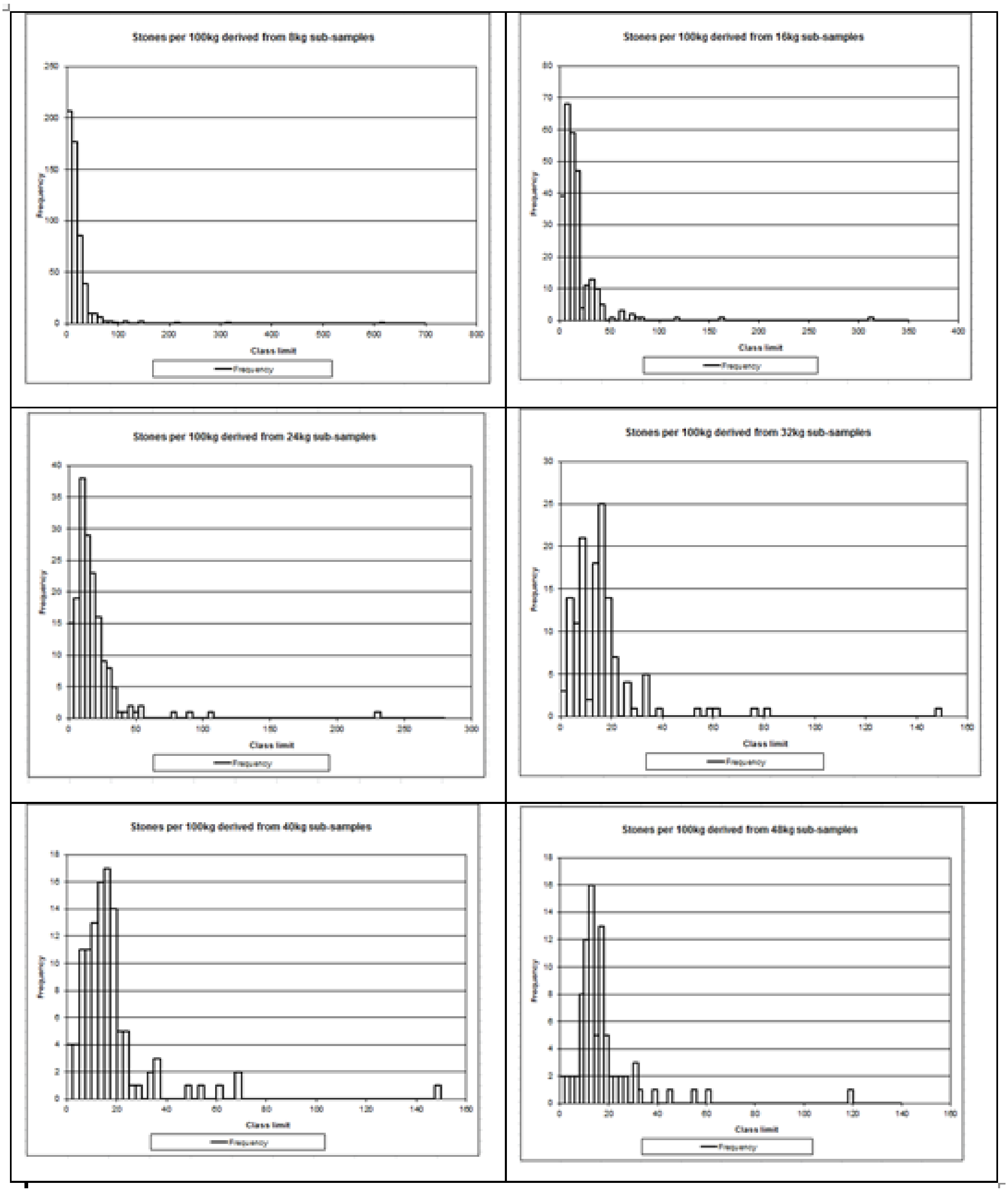


Figure 4-10 : Histograms of Sample concentrations per 100kg for all possible 8, 16, 24, 32, 40 and 48kg subsamples from Phase I and II sampling.

The histograms show that the number of barren subsamples decreases and the maximum stone concentration decreases with the increase in the size of the subsample. Further increases in sample size eventually result in a more symmetric stone density histogram, which is in line with the Central Limit Theorem.

Average diamond concentration varies between 16.99 and 17.20 stones/100kg (equivalent to 1.35 and 1.37 stones/8kg) for all size combinations. Apparent outliers are not eliminated from the reconstruction.

Changes in mean and variance of sample concentration with increase in subsample support size are shown in Table 4-5 and Figure 4-11.

Table 4-5 : Sample diamond concentration, Mean and standard deviation. Increase in sample support achieved by combining consecutive 8kg subsample sections down each hole.

Subsample support size (kg)	Mean concentration in stones / 100kg	Standard deviation
8	17.15	35.20
16	17.20	25.43
24	17.12	21.54
32	16.99	19.71
40	17.05	17.60
48	17.15	15.30

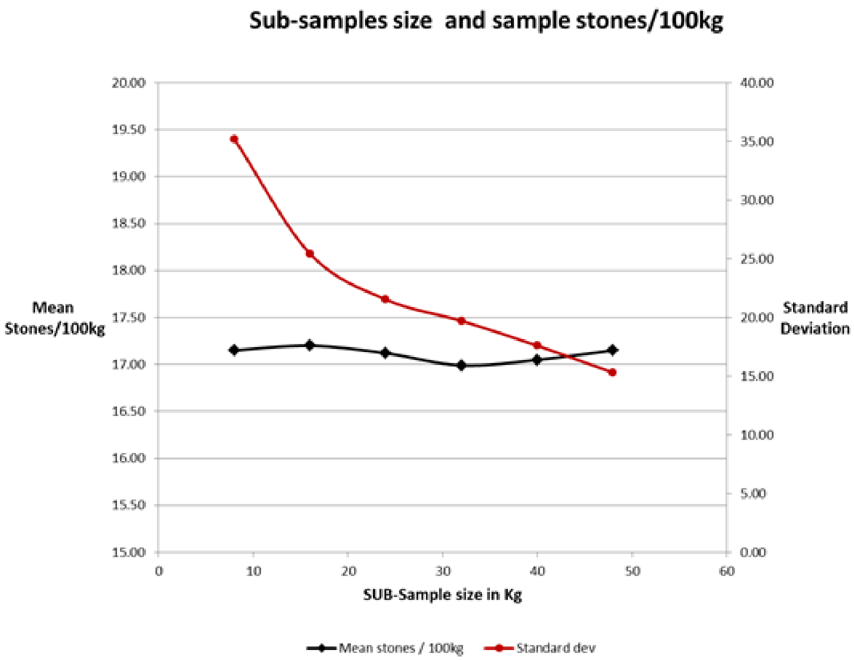


Figure 4-11: Mean and Standard deviation of diamond concentration with increase in subsample size.

A substantial reduction in variability of diamond concentration is achieved by increasing the size of subsamples to 48kg.

4.1.4.2 Spatial structure

An implication of the high variability of the smaller support subsamples is that spatial structure is obscured by the high variability of 8kg subsample values. This is shown by the variograms for 8kg and 32kg subsamples in Figure 4-12.

This is in line with section 3.1.4.1 but for a different reason. In this case the higher variability is due to the smaller support size of the 8kg subsamples, not because of a higher truncation level.

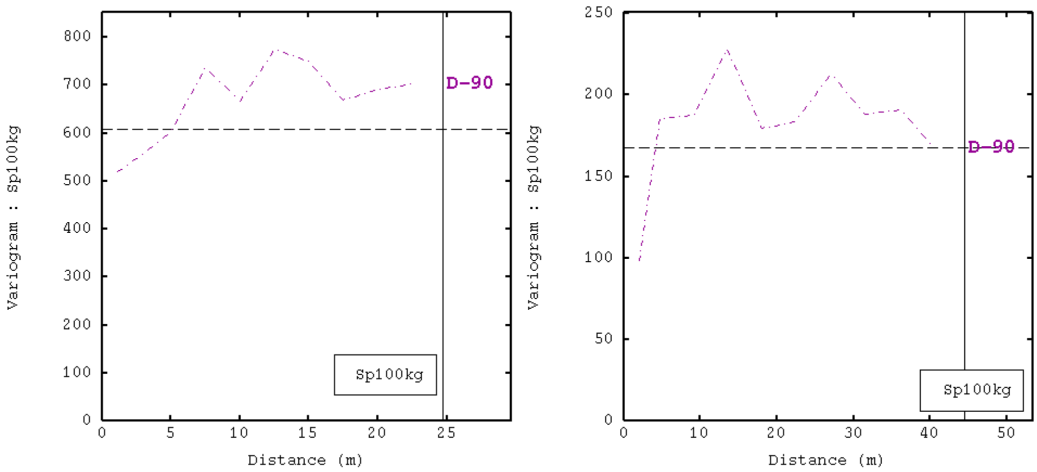


Figure 4-12 : Variograms for 8kg and 32kg subsamples. Variogram for the smaller subsamples on the left shows high nugget effect compared with variogram for combined subsamples on the right.

Everything points to the advantage of an increased subsample size for this deposit. The sampling method employed in this case study proved to be a 'safe' option with respect to subsample support size, by leaving it open for selection as any multiple of 8kg. If it is not feasible to treat all drill cores in this fashion, the same result could be achieved by storing sections adjacent to selected core sections for possible treatment at a later stage if required.

Sampling seems to be acceptable as far as diamond concentration is concerned. Not all producers go to the extremes of embarking on a 4.6tonne microdiamond sampling campaign. There is a danger of oversampling as may have been the case with this deposit.

Subsample support size is important to reduce variability in diamond concentration and to ensure that spatial structure is detectable if needed. Increase in the number of subsamples works in favour of unbiased estimates, while increased subsample size favours low variability in mean sample concentration.

If both aspects are acceptable then there will also be enough stones for size distribution modelling.

4.1.4.3 Number of subsamples

The effect of the number of 8kg subsamples per sample is examined by randomly composing samples by selecting groups of 8kg subsamples from the 547 subsamples in the total sample, beginning with 10 subsamples per sample and ending with 105. Sample size thus increases from 80kg to 840kg.

Selection takes place exhaustively to keep the influence of all subsamples the same. The number of possible samples therefore decreases with increased sample size. For each group of samples the size distributions were plotted and the minimum and maximum stone concentration recorded.

Results are shown in Table 4-6.

Table 4-6 : Dispersion limits for Diamond concentration with Sample size

Average sample size kg	Number of samples formed	Concentration as stones /100kg		
		Mean	Minimum	Maximum
79	54	17.2	3.7	74.5
159	27	16.8	9.5	45.3
238	18	17.1	10.1	43.2
318	13	17.4	9.8	35.4
397	10	17.3	9.7	30.6
477	9	17.2	12.6	26.3
842	5	16.9	13.6	19.9

The values in Table 4-6 are depicted in Figure 4-13. The graph is similar to Figure 4-11 that reflects the effect of an increase in subsample <u>size</u>. This figure however shows the variability of sample concentration with respect to the <u>number</u> of subsamples.

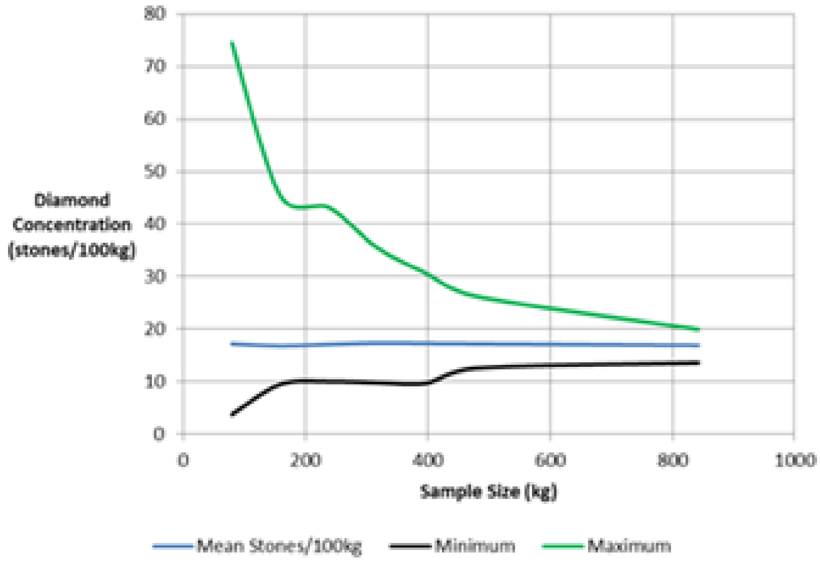


Figure 4-13 : Mean and dispersion of sample diamond concentration with sample size. The more subsamples in the sample, the more accurate the sample mean concentration. Mean stones/100kg is the mean of all sample concentrations in the size group, likewise for minimum and maximum. It seems more likely to overestimate than to underestimate diamond concentration from a small sample.

A measure for diamond size was not calculated, but sample LP-curves were plotted for all samples from each sample size group. The behaviour of the diamond size distribution with an increase in sample size is illustrated in the series of graphs in Figure 4-14.

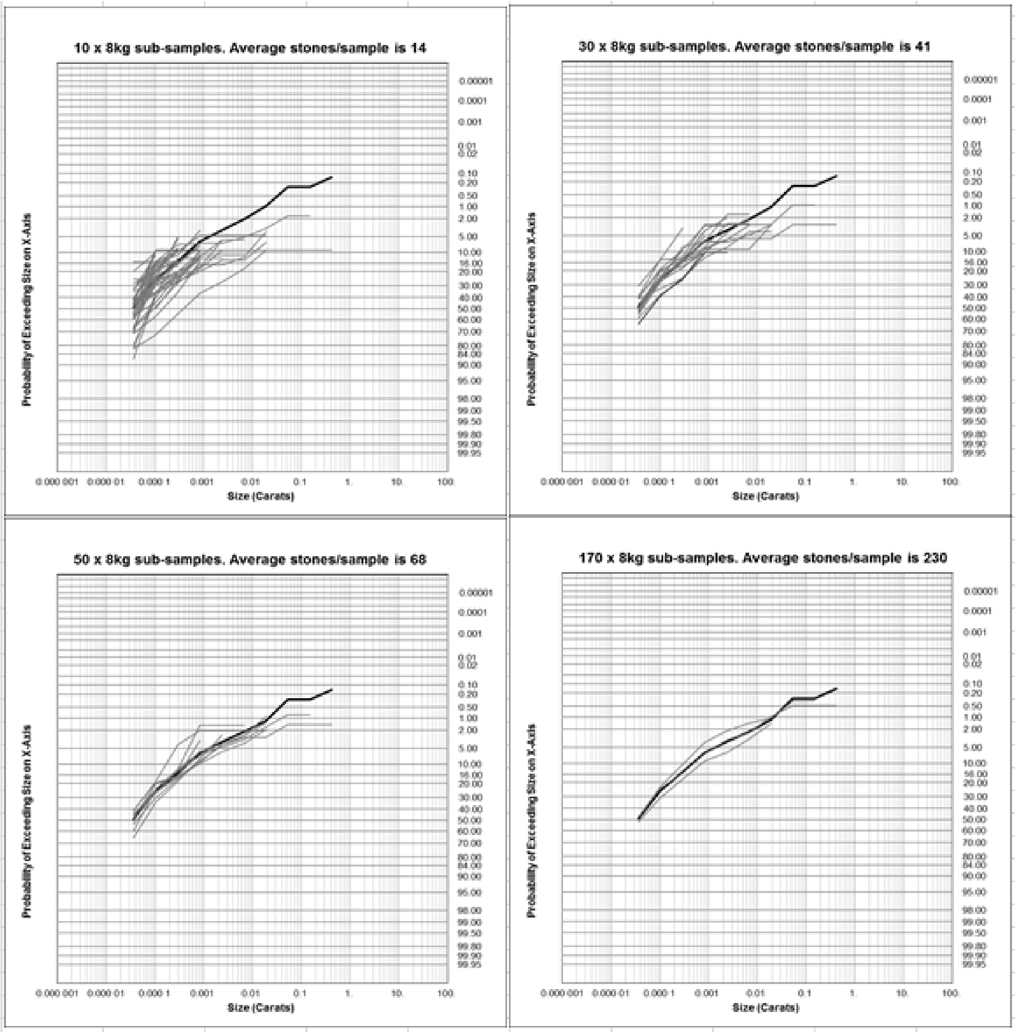


Figure 4-14 : LP-graphs for samples formed by combining an increasing number of subsamples. The more subsamples and stones in the samples, the closer their size distributions are to the actual.

The graphs are all based on fewer stones per sample than would normally be recommended for reliable size distribution modelling.

The final graph in the lower right hand corner of Figure 4-14 represents a split of the total sample into three equal parts with each part yielding approximately 220 stones each, and still shows that there is some variation between the resulting size distribution graphs.

The sample lying between the two extreme samples coincides with the total sample. The total sample comprising 547 subsamples from 8 holes with weight of 4.6t and yielding 843 stones probably represents the diamond size distribution and diamond concentration reasonably well.

4.1.4.4 Conclusion of sampling assessment

The combined 840kg sample provides diamond recovery suitable for an early assessment of diamond content.

The diamond size distribution model is still doubtful even after 4.6 tonnes of sampling.

The coarse diamond size distribution and grade of 13cpht warrant further interest in this kimberlite, but interest is shifted towards diamond value. Macrodiamonds are required and bulk sampling is the next sampling phase.

Bulk sampling will yield macrodiamonds without any doubt, and will remove any uncertainty that remains with respect to diamond size. If diamond quality is reasonable, then average revenue in terms of Dollar per carat will be high and average value in terms of Dollar per tonne should be reasonable.

In hindsight it is concluded that microdiamond sampling should have stopped at a total weight of 1.6tonnes. After the second 800kg batch of subsamples it should have been clear where this deposit was headed. The rest of Phase II should then have been replaced by limited large diameter drilling for macrodiamonds. Large diameter reverse-circulation drilling with conventional DMS sample treatment at a bottom cut-off of 0.5mm would be suitable to recover macrodiamonds for confirmation of diamond size distribution and valuation for revenue estimation.

4.1.4.5 Uncertainty

Average sampling grade is calculated at 0.35carats per tonne, based on carats recovered above +1.18mm. The presence of a 1.15-carat stone elevated sampling grade and with only 9 stones occurring above 1.18mm the sampling grade is highly variable.

Grade obtained from the diamond content model based on the entire sample parcel is more reliable. Comparison of the model and sampling size distributions suggests that the model is pessimistic rather than optimistic.

A slightly coarser diamond size distribution (model 2) leads to a grade estimate of 25cpht at +1mm, emphasising the reason for more interest in this body. The associated LC-model is shown in Figure 4-15 along with the more pessimistic estimate (model 1) of 13cpht.

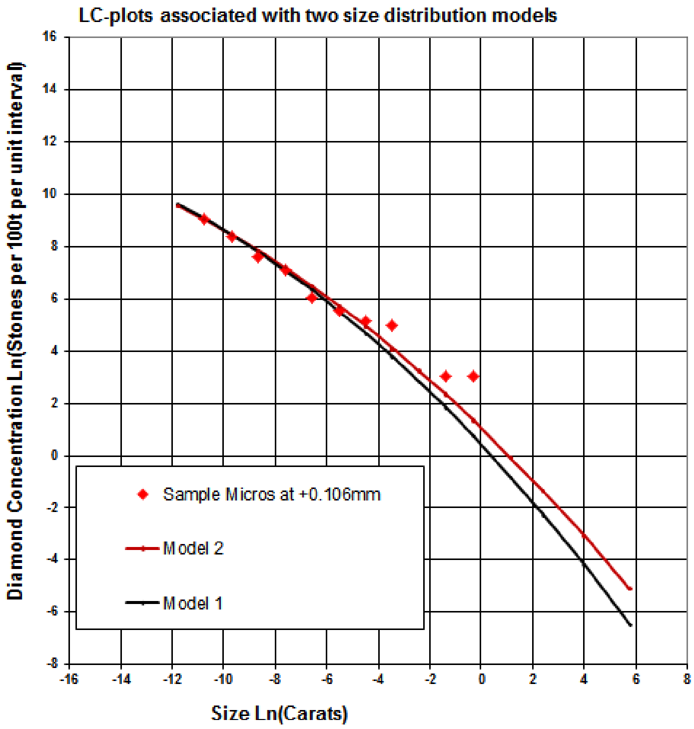


Figure 4-15 : LC-models for two size distribution models. Model 1 suggests a grade of 13cpht and model 2 a grade of 25cpht at +5diamond sieve bottom cut-off. The need for confirmation of the models by means of macrodiamond sampling is clear.

With the main interest shifted towards diamond value a bulk sampling program would be a logical next step. Macrodiamonds will then provide a firm diamond size distribution model and grade estimate.

4.1.5 Conclusions

The coarseness of the size distribution model justifies further work on the kimberlite to obtain diamond revenue information. The preliminary size distribution model suggests an unusually coarse diamond size distribution, implying that average diamond value will tend to be high if the diamond assortment contains moderately high quality stones. As a consequence, value per tonne could be high in spite of the low diamond concentration. A next sampling phase aimed at macrodiamond recovery for diamond valuation is therefore recommended and will also serve as a means to confirm the size distribution model.

This extreme case serves to illustrate the need for sufficient numbers of stones for diamond content modelling. The economic viability of the deposit is dependent on diamond value, which in view of the coarse size distribution, does not need to be extraordinarily high to yield high average diamond value.

The last column in Table 4-3 shows that an average of approximately 500 stones will be recovered above 0.6mm at a sample support size of 96 tonnes, yielding stones up to and above 3 carats. National Instrument N43-101[20] specifies that a diamond parcel comprising 2000 carats is required from a deposit for the associated resource to be assigned the Indicated category. This implies some 10,000 tonnes of material for a deposit with a grade of 0.2 carats per tonne. In lieu of such size parcel it is still possible to obtain value estimates to demonstrate eventual economic extraction potential to be able to declare an Inferred resource.

With time, the nature of the diamond assortment from the deposit will determine the sample size required in this case, but before then the main focus of sampling should be to determine a reliable diamond content estimate.

For a typical recovery process operating at a bottom screen equivalent to +5 diamond sieve a resource grade of approximately 0.13 carats/ton or 13 cpht is estimated. The estimate assumes no diamond recovery below and full recovery above +5 diamond sieve, but has to be confirmed by more sampling.

The existence of a single geological domain is confirmed.

A coarse diamond size distribution and low diamond concentration of less than 2 stones per 8kg is confirmed. There is little difference between recoveries at +0.85 and +1.18mm.

It is concluded that this is not a kimberlite that should be abandoned in spite of its low diamond concentration. More sampling is recommended to obtain macrodiamonds.

[20] Canadian Institute of Mining, Metallurgy and Petroleum – Standards on Mineral Resources and Reserves

4.2 Case Study 2

4.2.1 Project background

A kimberlite with high diamond concentration is selected to illustrate a more ideal case for microdiamonds.

The deposit is situated in a highly undulated topography in a remote location with difficult access. The setting is ideal for the use of microdiamond sampling for an initial assessment of diamond potential and progression towards advanced sampling and feasibility studies.

Sampling took place in two phases. Phase I was based only on microdiamonds and commenced with a single sample, followed by sampling from a larger part of the body. The author was not involved with this deposit prior to receiving the results of Phase I sampling.

Phase II was instigated in response to recommendations made on the basis of Phase I results. Sampling commenced shortly after the results of Phase I had been analysed with the focus on the recovery of more microdiamonds, complemented by macrodiamonds.

Additional microdiamond sampling was suggested to cover a larger part of the deposit. Macrodiamond sampling was recommended to confirm the size distribution model derived from microdiamonds and to take a step towards diamond value.

4.2.2 Phase I Sampling and Estimation

4.2.2.1 Sampling data

Sampling was focused on microdiamond recovery. The purpose of this sampling phase was to obtain an initial assessment of diamond content and to decide on possible guidelines for further sampling, which was expected to entail bulk sampling for macrodiamonds.

Sampling comprised 1,352kg of kimberlite material in the form of six samples collected at varying surface elevations within the kimberlite. Samples weighed between 160kg and 240kg and were treated in 8kg subsamples by means of Caustic Fusion, yielding 2,643 stones above 0.075mm.

Stone concentration at +0.106mm bottom cut-off is similar for the six samples at an average of 46 stones per 25kg. Stones were sieved in mm size classes down to a bottom screen size of 0.075mm mesh

Core drilling for additional information on kimberlite geometry and internal geology indicates the same geological footprint from the different depth levels of sampling.

Data is summarised in Table 4-7 and gives the impression that this may be a deposit with high diamond potential.

Table 4-7 : Phase I microdiamond sampling.

Sample number	T1	T2	T3	T4	T5	T6	Total
Sample weight kg	223	167	230	224	240	268	1352
Screen size mm	stones per size class						
1.700	0	0	0	0	0	0	0
1.180	1	0	1	0	3	1	6
.850	9	4	7	4	4	6	34
.600	19	8	19	17	16	10	89
.425	33	21	36	27	40	30	187
.300	56	34	63	76	55	61	345
.212	94	49	79	81	80	143	526
.150	106	80	88	84	124	150	632
.106	103	80	119	123	166	72	663
.075	111	20	7	3	15	5	161
Total +0.075mm	532	296	419	415	503	478	2643
Stones/25kg +.106mm	47	41	45	46	51	44	46
Stones/25kg +.3mm	36	29	32	32	34	37	34

Recovery results below 0.106mm is irregular due to changes in bottom cut-off implemented during the sampling campaign.

4.2.2.2 Diamond size

Analysis was performed on individual samples and the combined sample.

With the apparent recovery differences in the smaller size classes in mind, size distributions were plotted at increasing bottom truncation as shown in Figure 4-16.

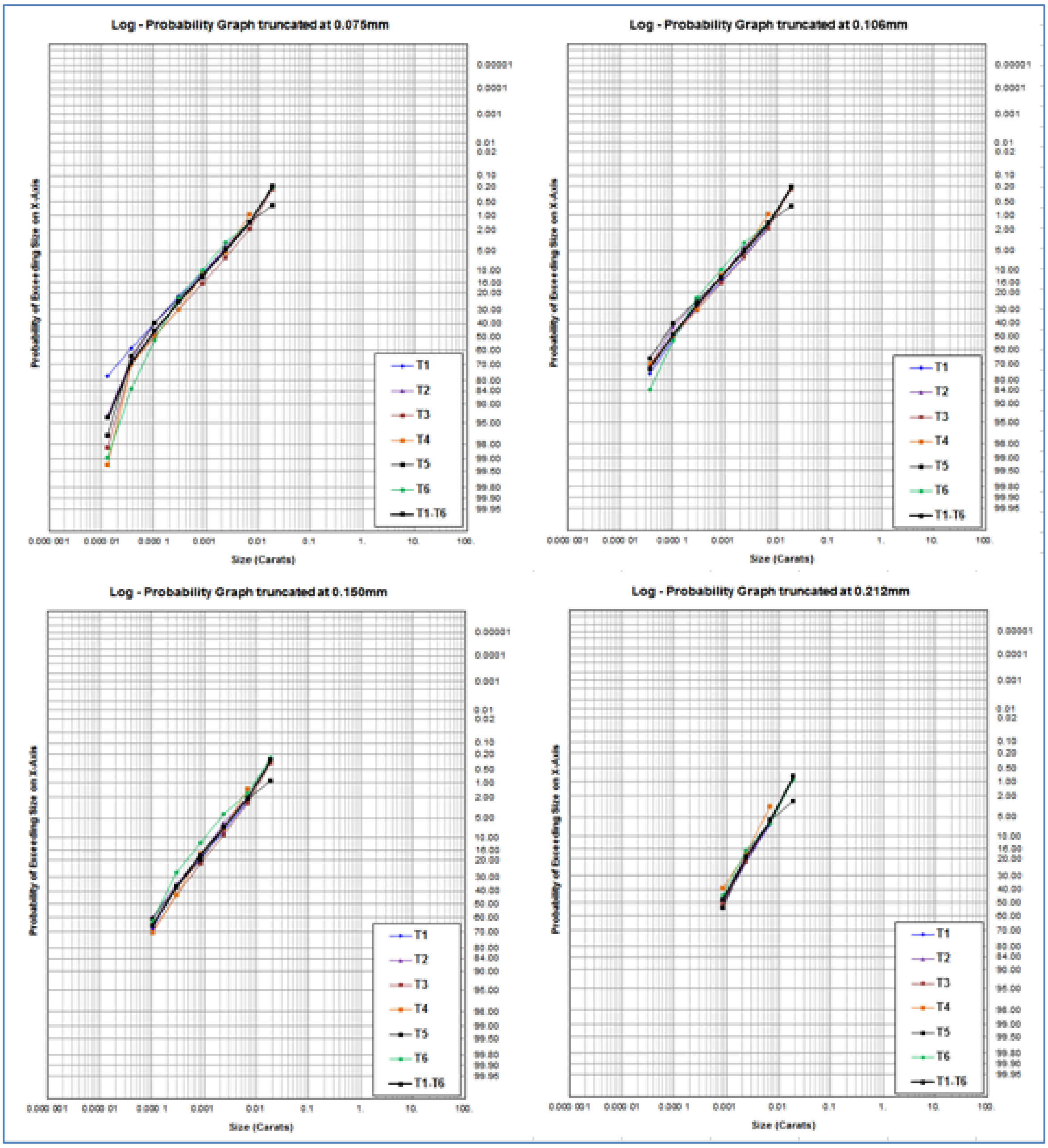


Figure 4-16 : LP-graphs at bottom truncation of +0.075, +0.106, +0.150 and +0.212mm from left to right and top to bottom

The first graph is for samples at +0.075mm and shows evidence of the higher stone count below 0.106mm in sample T1, shown in Table 4-7.

The second graph is for samples at +0.106mm, showing the lack of stones in the +0.106 size class for T6.

The third graph shows recovery above +0.150mm and highlights the high stone count for T6 in the +0.212mm size class.

The size distributions above 0.3mm are similar as shown in the last graph which shows recoveries truncated at 0.3mm.

During the course of analysis it became evident that the higher stone counts for sample T1 below 0.106mm is due to a change in bottom cut-off after this sample had been treated. Analysis was consequently performed on recoveries above 0.106mm.

Being at a phase where there still is no macrodiamond recovery from bulk sampling, the differences between the samples are noted without initiating separate analyses. The differences above 0.106mm are assumed to be due mainly to erratic performance of the recovery process, as some differences between samples appear restricted to single size classes. Furthermore, in view of the geological similarity reported for samples, the combined sample was used for diamond content modelling.

The log-probability graph for the combined sample is shown in Figure 4-17.

A two parameter lognormal distribution with parameters (μ=0.000532, σ=0.0084) was fitted to the data and a typical diamond parcel (500,000 stones) based on these parameters plotted with the sampling data.

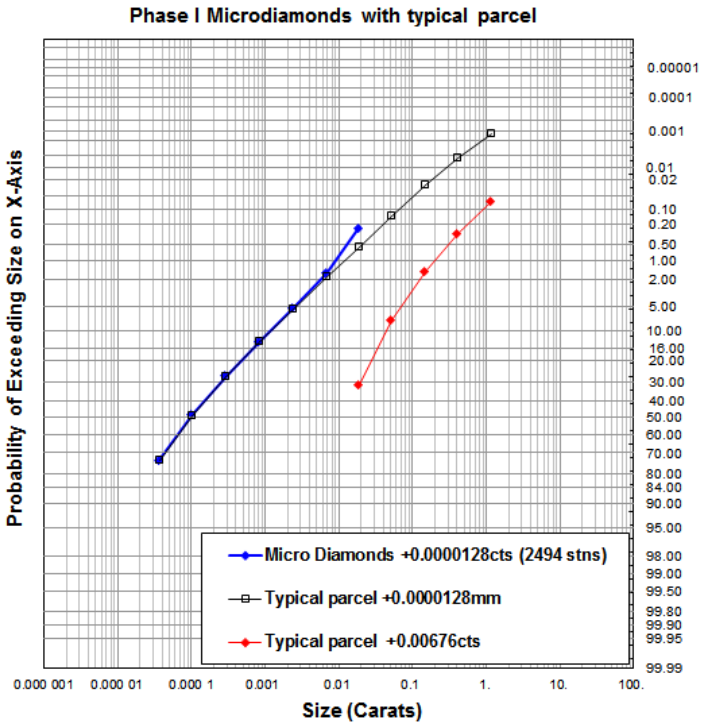


Figure 4-17: Log Probability distribution based on Phase I microdiamonds

Figure 4-17 shows the combined sample size distribution truncated at a bottom size of +0.106mm (0.0000128cts), with the simulated typical parcel at the same bottom truncation and at +0.85mm (0.00676cts). Close correspondence between sample and simulation at common cut-off indicates that the model is satisfactory to represent the diamond size distribution.

The size distribution curve for the typical parcel extends towards the larger diamond size classes in the diamond size range since it contains more diamonds than the sample. The more diamonds generated in the typical parcel, the more likely the parcel is to contain larger stones, relatively within the bounds allowed by the size distribution.

The smallest size class (+0.075mm) was left out of the modelling procedure to eliminate most of the recovery losses due to bottom screening. The irregularities mentioned earlier in this section do not seem to have any effect on the combined size distribution.

The deviation of the sample curve from the model at the top of the sample graph relates to the size of the sample. The number of stones (6) recovered above 1.18mm under-represents the frequency expected under model assumptions and causes the deviation. The deviation is also exaggerated by the scale used on the Y-axis.

The graph in Figure 4-18 demonstrates the higher variability of the size distribution in the larger size classes occurring in simulated samples of this size.

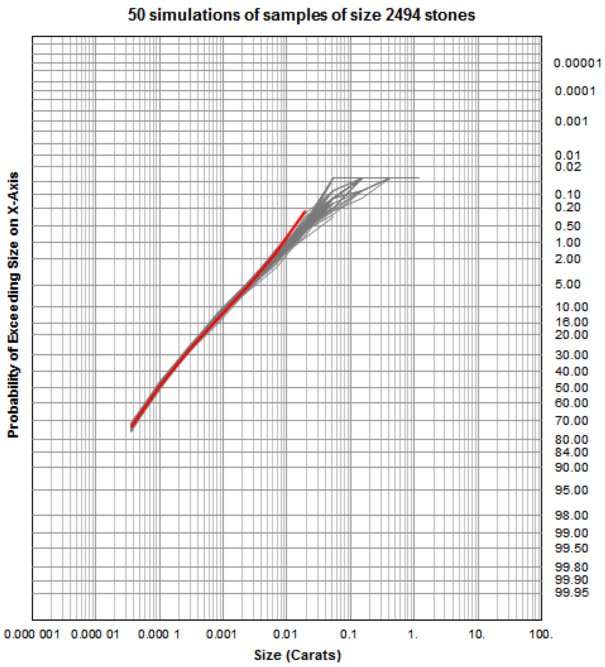


Figure 4-18: 50 Simulated samples of 2,643 stones based on size parameters fitted to the microdiamond sample shown with the sample distribution in red.

With such a close spread of size distributions for samples of this size it could safely be assumed that this size sample should give a realistic reflection of the population diamond size distribution, provided that sampling is representative of the domain.

4.2.2.3 Diamond content

Diamond content modelling was based on a sample stone count of 1.84 stones per kg and the size distribution model obtained in Section 4.2.2.2. A typical sample comprising 1million 25kg microdiamond samples was simulated, yielding a total microdiamond sample weight equivalent to 25,000 tonnes.

Each 25kg subsample was allocated a number of +0.106mm stones in accordance with a random number drawn from a Poisson distribution with mean 46, which is the average diamond concentration calculated for the combined sample.

The characteristics of the diamond population as per sampling were thus contained in the simulated sample, forming a typical parcel which was used to quantify diamond content by size class.

LC-curves for typical parcel and combined sample are shown in Figure 4-19, indicating close correspondence between the two parcels, except for the last size class.

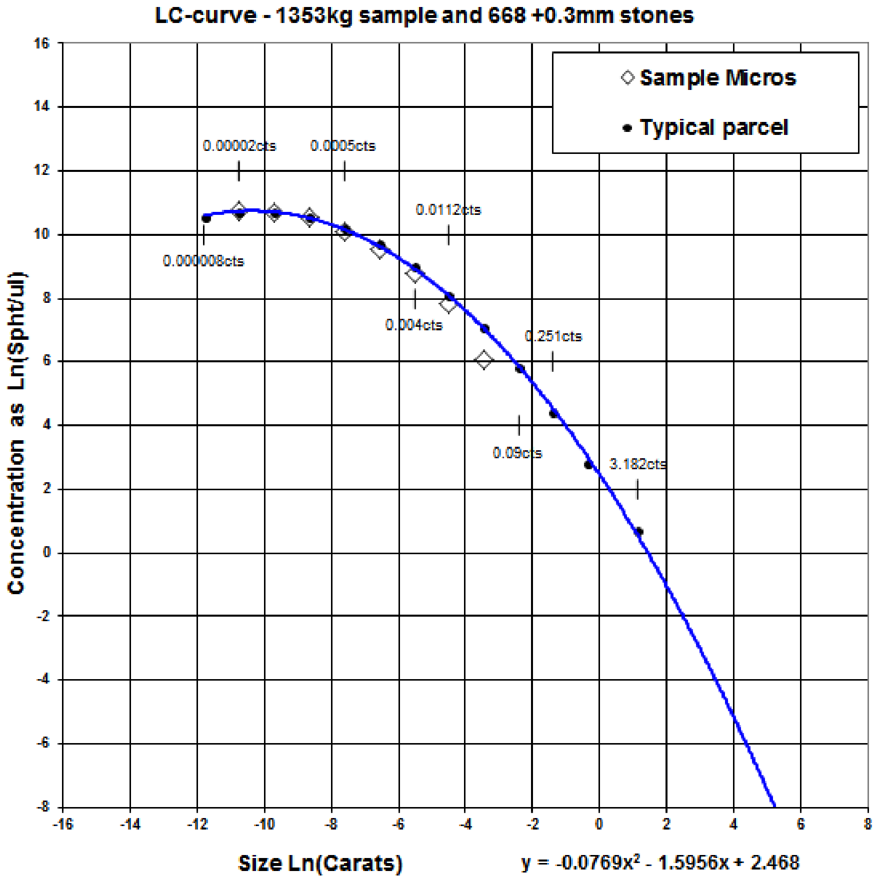


Figure 4-19 : Diamond concentration model (LC-curve) showing typical parcel and microdiamond sampling points. Stones assigned to mm size classes only.

The typical parcel LC-curve is used to derive a diamond content estimate for the deposit. Grades truncated at +0.85mm (0.007cts) and +1.18mm (0.019cts) were estimated at 90cpht and 60cpht respectively.

It remained to confirm the extrapolated model for diamond size with the size distribution of macrodiamonds from a bulk sampling phase.

4.2.2.4 Confidence limits

The close correspondence between model and sample concentration distributions suggests high confidence in the diamond grade estimates.

Simulation results depicted in Figure 4-20 and Figure 4-21 are based on a size distribution similar to the model for this project with diamond concentration equivalent to 37 stones per 20kg, which is equivalent to the 46 stones per 25kg for this deposit. The 10% and 90% percentiles derived from the graph are therefore applicable to this case study.

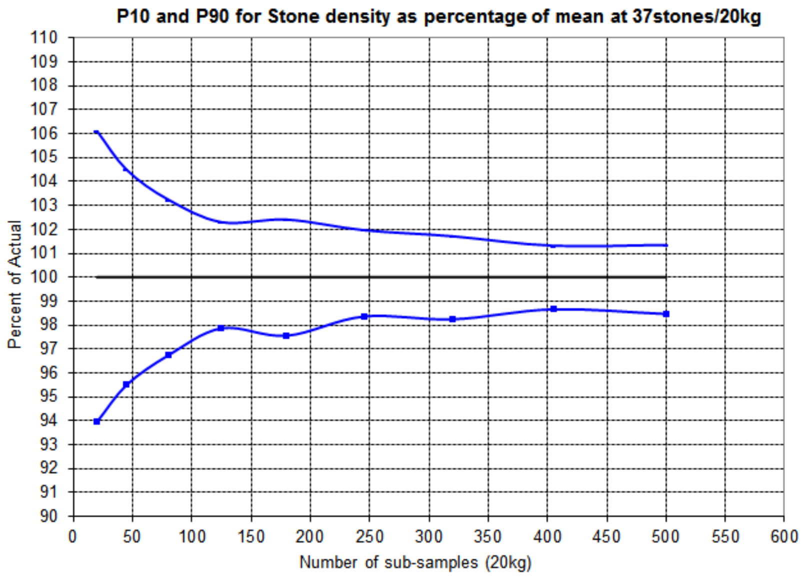


Figure 4-20 : Upper and lower Confidence bands for diamond concentration

The 1,353kg sample is equivalent to 67 x 20kg subsamples, implying that the 10th and 90th percentiles for sample concentration are within 3% to 4% of the actual mean according to the graphs in Figure 4-20.

With almost 2,500 stones in the combined sample the simulation results in Figure 4-21 suggest the percentiles for the combined sample size distribution mean and standard deviation are within 2% and 5% of the actual values.

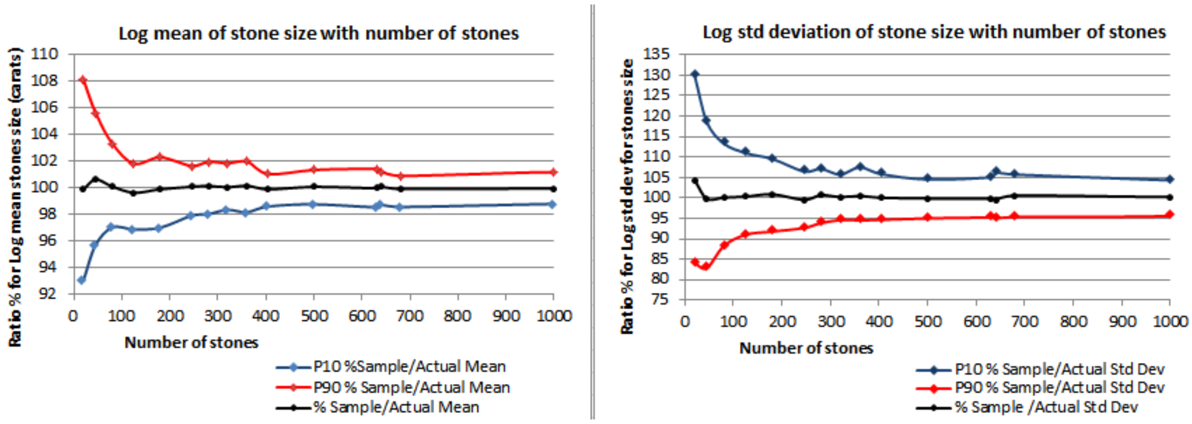


Figure 4-21 : Confidence bands for mean and standard deviation of stone size distribution

10% and 90% extreme parameter values shown in Table 4-8 were obtained by implementing the upper and lower limits for diamond size and concentration.

Table 4-8 : 10% and 90% percentile limits for size and concentration parameters.

	Concentration stones/20kg +0.106mm	Mean of log (stone size)	Std dev of log (stone size)	Grade at +0.85mm Cpht	Grade at +1.18mm Cpht
Model	37	-10.30	2.35	90	60
Lower 10%	35	-10.40	2.23	50	30
Upper 90%	38	-10.20	2.47	160	120

Parameter values shown in the table were used to create corresponding typical parcels for which the concentration-size graphs are shown in Figure 4-22. Grades associated with the 90% upper and 10% lower LC-curves in the figure are listed in Table 4-8 above.

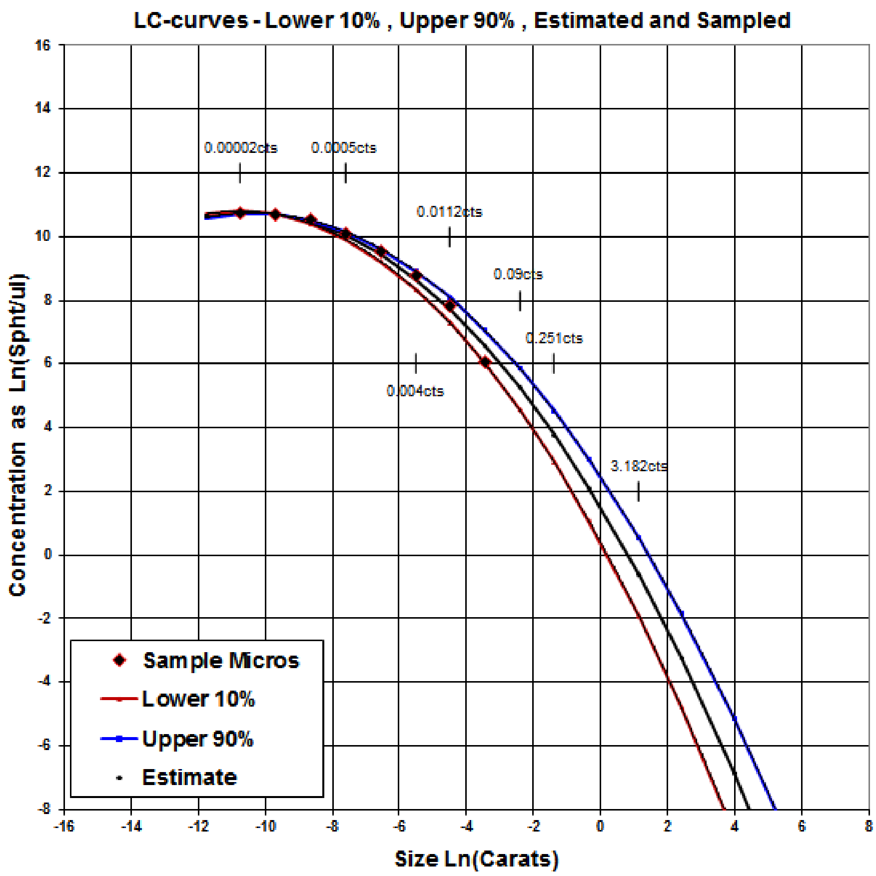


Figure 4-22 : Simulated upper 90% and lower 10% percentile bands for the distribution of diamond concentration, shown with combined sample and assumed model estimate.

4.2.2.5 Results and recommendations

Grades estimated at 90cpht and 60cpht above 0.85mm and 1.18mm square mesh were good reasons to embark on a sampling campaign to recover macrodiamonds for valuation purposes, also serving as confirmation of the size distribution model based on microdiamond sampling results.

The following is derived from Phase I sampling on the assumption that the diamond content model accurately reflects the deposit:

- A next sampling phase will have to focus on improving spatial representation of the deposit by means of microdiamond sampling and providing +1mm diamonds for valuation by means of bulk sampling.
- Based on an estimated grade of 0.6 carats per tonne above +1.18mm bottom cut-off a sample of 1,600 tonnes will yield 1000 carats.
- From this size sample some 140 carats will occur above 3.35mm or approximately the equivalent of +11 diamond sieve in the DTC sieving system.
- This may not be sufficient to comply with industry regulations, but it will be more than enough to provide strong indications of average diamond value.[21]
- More microdiamond samples may be collected, either from existing core or from core that will have to be drilled to improve deposit geology and geometry.
- Addition of macrodiamond data will provide more confidence in diamond size distribution parameters and should reduce the difference between the 10% and 90% percentile limits for grade.

4.2.3 Phase II

4.2.3.1 Sampling data

Phase I sampling was followed by a bulk sampling program for macrodiamonds with sample excavation taking place in the form of surface trenches. Three trench samples were excavated and yielded 329 carats from 790 tonnes of kimberlite. This is less than the 500cts expected from 800tonnes after analysis of Phase I sampling results since recovery took place at +1.5mm bottom cut-off. Results are summarised in Table 4-9.

Table 4-9 : Summary of Bulk sampling data

Sieve	Bulk 1		Bulk 2		Bulk 3		Total	
	Carats	Stones	Carats	Stones	Carats	Stones	Carats	Stones
DTC+15	2	3	3	2	1	1	6	6
DTC+13	3	4	2	3	1	2	6	9
DTC+11	11	32	13	39	11	33	35	104
DTC+9	15	84	19	100	14	77	49	261
DTC+7	12	105	18	148	14	119	44	372
DTC+5	37	590	46	690	40	628	123	1908
DTC+3	15	455	23	645	15	428	52	1528
DTC+2	4	164	5	207	2	98	11	469
DTC+1	1	48	2	99	1	32	4	179
Total	100	1485	130	1933	99	1418	329	4836
Average size	0.067		0.067		0.070		0.068	
Tonnes	250		260		280		790	
Carats/100t	40		50		36		42	
Stones/ton	6		7		5		6	

Diamond concentration averages at 6 stones per tonne at DTC +1 bottom cut-off sieve. This cannot be compared with the microdiamond concentration at +0.106mm bottom cut-off, except by plotting their concentration graphs on the same log axis, shown in the next section (4.2.3.3).

[21] Industry requires 2000 to 3000 carats for a resource to reach the indicated level of classification, but this is a general rule which may not apply in a case where the diamond assortment is less variable. On the other hand it may not be sufficient in the case of a highly variable diamond assortment.

4.2.3.2 Diamond size

Bulk sample recovery was added to Phase I diamond size frequency and concentration distributions and used to update the models. Figure 4-23 shows microdiamond- and macrodiamond sampling data, each compared with typical parcel truncated at bottom screen size corresponding to sampling.

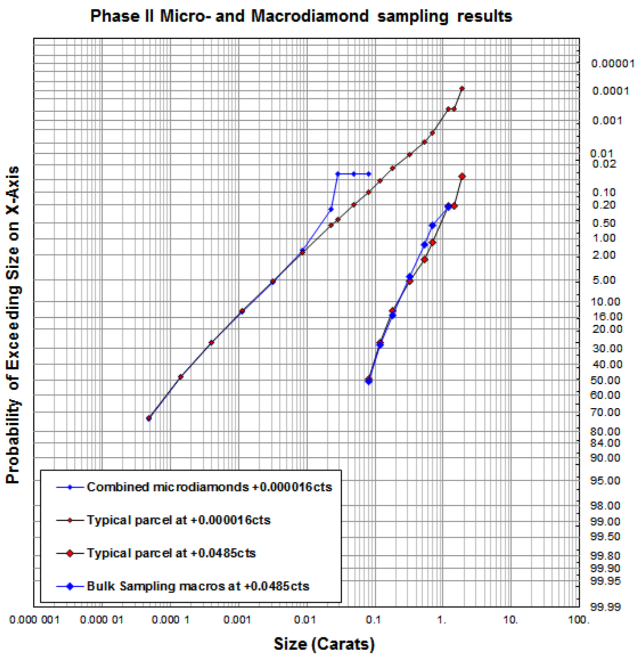


Figure 4-23 : LP-graphs for diamond size, an update of the Phase I distribution with macrodiamonds from Phase II bulk sampling.

The initial diamond size distribution model based on Phase I microdiamond data remains almost unchanged. This means that diamond content estimated on the basis of Phase I microdiamond data is coherent with macrodiamonds recovered from Phase II bulk sampling.

Furthermore, bulk sampling provides recovery information suitable for calculation of bottom cut-off alignment factors and recoverable diamond content.

4.2.3.3 Diamond concentration

The updated diamond size distribution and Phase I microdiamond concentration rate were used to simulate a typical diamond parcel for comparison with all available micro- and macrodiamond data. Figure 4-24 shows LC-graphs for the two sampling types and the simulated typical parcel.

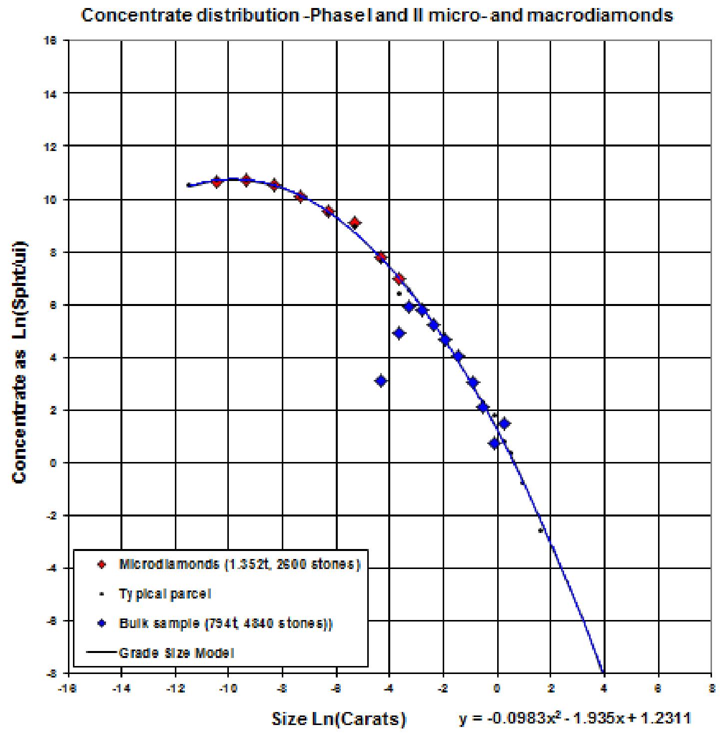


Figure 4-24 : Diamond concentration with size based on Phase I and II micros and macros. Stones assigned to mm size classes up to 0.60mm, then in DTC sieve classes.

The points on the graph deviating from the model curve represent bulk sample recoveries in the lower three size classes. Recovery in these classes was affected by application of a bottom cut-off at +5 DTC diamond sieve. Deviation of a sample point from the model curve represents the loss in that size class due to screening and diamond lockup and will be typical of diamond recovery in the bulk sampling treatment plant.

The LC-curve based on microdiamond sample size and stone concentration fits both sets of data and implies coherence between microdiamond and bulk sampling results, both with respect to size distribution and diamond concentration.

Slight changes to the LC-model resulted in increases in diamond grade estimates from 90cpht and 60cpht to 92cpht and 63cpht respectively, at +0.85 and +1.18mm bottom truncation levels. (The difference is immaterial but exact values are quoted to correspond with the total in Table 4-10).

4.2.3.4 Confidence limits

Variation in the parameters for diamond size distribution is all but eliminated by the macrodiamonds from bulk sampling. The size distribution based on Phase II sampling results is not much different from the distribution derived from Phase I microdiamond data.

Diamond concentration could still vary, as sampling material originates from at a total of 9 deposit localities only. If diamond concentration behaves according to the simulated graph in Figure 4-20, then deposit grade is estimated to lie within 4% of the sample mean. Therefore grade is estimated at between 90cpht and 100cpht for recovery at +0.85mm truncation, and between 63cpht and 68cpht for recovery at +1.118mm. This does not mean that the grade for any amount of sampling material will lie between these limits.

For smaller batches of material the grade will vary in accordance with the images shown in Figure 4-20 and Figure 4-21. The smaller the batch of material treated the larger the variance will be. If the entire deposit is treated the average grade is expected to lie between the limits specified.

4.2.3.5 Recoverable diamond content

Grade estimates of 92cpht and 63cpht at +0.85 and +1.18mm are based on strict truncation levels. However, application of a bottom cut-off is different from strict truncation in that it suggests physical sieving, which is associated with screening and lockup losses. In order to obtain recoverable diamond content bottom cut-off alignment factors are required to emulate the associated losses that occur during recovery.

If treatment and recovery conditions during mining are anticipated to be the same as during bulk sampling the same alignment factors will be applicable. Therefore, deviation from total diamond content (or in situ content) seen for recovery in the smaller size classes in Figure 4-24 is at this stage assumed to occur during mining as well.

With total diamond content known from the model, alignment factors are calculated by comparison with bulk sample recoveries in the bottom size classes. On this basis a recoverable grade for production and treatment in a facility similar to the bulk sample treatment plant is estimated at 47cpht, compared with the average bulk sample grade of 42cpht. In situ and recoverable diamond grade is given in Table 4-10.

The factors shown in the table represent the proportion of in situ stones in the size class that actually reaches the sorting table. These factors stand to be revised when more details are known about the treatment parameters to be used in the production plant.

The table shows a breakdown by size class and includes average diamond value as estimated from bulk sample macrodiamonds. Alignment factors to arrive at recoverable grades are shown by size class.

Table 4-10 : In situ and recoverable grade by size class, including alignment factors, average diamond value, Revenue in Dollar per tonne and average value in Dollar per carat.

Size Class	In Situ Grade cts/tonne	Alignment factor	Grade in cts/tonne	%cts	Dollar / Carat	Dollar / tonne
60+	0.0000	1	0.000	0.015	429	0.03
45+	0.0001	1	0.000	0.012	429	0.02
30+	0.0002	1	0.000	0.035	429	0.07
20+	0.0003	1	0.000	0.059	429	0.12
15+	0.0003	1	0.000	0.072	429	0.15
+23	0.0012	1	0.001	0.250	429	0.51
+21	0.0044	1	0.004	0.944	309	1.37
+19	0.0086	1	0.009	1.836	232	2.00
+17	0.0064	1	0.006	1.363	193	1.24
+15	0.0047	1	0.005	0.996	177	0.83
+13	0.0206	1	0.021	4.378	151	3.11
+12	0.0162	1	0.016	3.450	129	2.09
+11	0.0383	1	0.038	8.139	109	4.16
+ 9	0.0642	1	0.064	13.654	87	5.58
+ 7	0.0641	1	0.064	13.628	71	4.57
+ 6	0.0725	0.9	0.065	13.876	60	3.94
+ 5	0.1106	0.8	0.088	18.809	50	4.45
+ 3	0.1411	0.5	0.071	14.997	41	2.88
+2	0.0670	0.22	0.013	2.848	17	0.23
+1	0.3003	0.01	0.003	0.639	14	0.04
	0.9210		0.470	100.000	80	37.39

The information in the table was used to demonstrate the sensitivity of grade and revenue to the level of bottom truncation.

Total recoverable diamond value (Dollars) and weight (Carats) were calculated at increasing bottom truncation levels and the resulting grade and revenue values were plotted as shown in Figure 4-25.

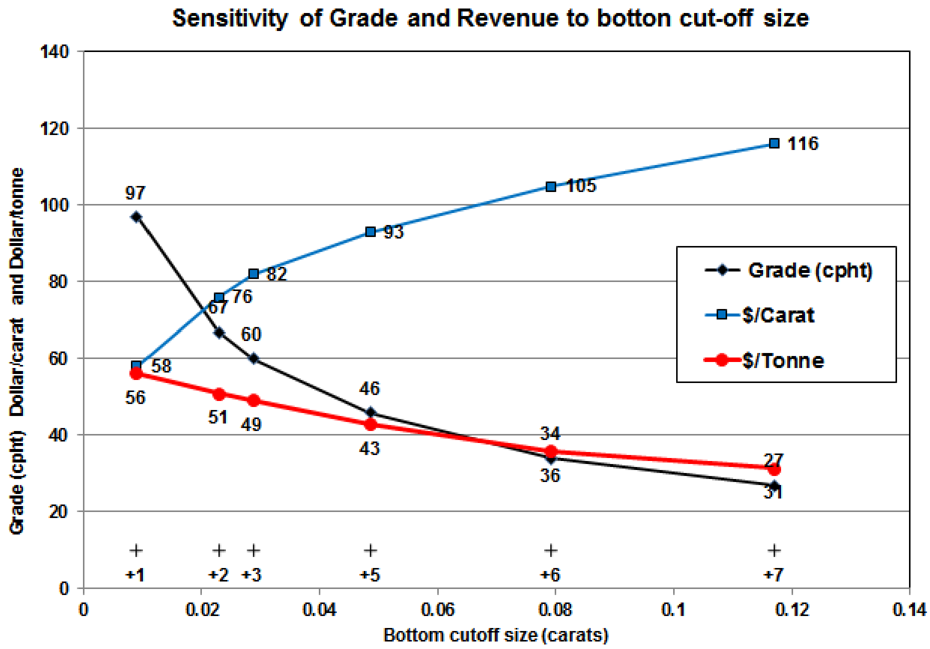


Figure 4-25 : Sensitivity of grade and value to bottom truncation

The following observations were made:

- The graph shows a sharp decrease in grade and increase in Dollar per carat value when bottom truncation level is lifted from +1 to +3 diamond sieve.
- The associated revenue in Dollar per ton decreases more moderately.
- The decrease in revenue gives an indication of the loss that can be tolerated by recovering diamonds at the higher bottom cut-off. Inversely, the gain by lowering the bottom cut-off is as demonstrated.
- However, it is not a simple matter, since attempting to recover smaller stones may also affect the recovery of larger stones. Such detail is not in the scope of the thesis.

The body considered is a single kimberlite family with diamond assortment characterised by the modelled size distribution. Value is derived from valuation of all available bulk sample macrodiamonds.[22]

It will be possible to declare an Inferred resource to the depth covered by sampling. The assessment as it stands provides a reliable estimate for diamond content. Combined with average diamond value and basic detail about deposit geology and geometry, possible eventual economic extraction can be demonstrated.

[22] Valuation detail is irrelevant in this text and is not provided.

The case study demonstrates how a positive result from microdiamond sampling quickly motivates follow-up bulk sampling that can transpire into a reliable assessment of diamond grade and value, within two sampling phases. It is shown that reliable estimates for diamond content based on microdiamond sampling is possible if sufficient diamonds are recovered.

5 Case Studies II

Résumé

Deux autres cas d'étude sont présentés dans ce chapitre.

Le premier cas d'étude est un gisement constitué de deux domaines kimberlitiques de salissages différents . Microéchantillons et macroéchantillons sont utilisés pour estimer la concentration en pierres et leur valeur.

La modélisation de la taille des pierres et de leur concentration se fait sur la base d'une kimberlite non salie. Un facteur moyen de salissage est déterminé par domaine à partir des analyses effectuées mètre par mètre le long de tous les sondages du gisement. La concentration effective en diamants s'obtient alors en tenant compte du salissage.

Les macrodiamants fournis par les échantillons en vrac sont utilisés pour valider la modélisation de la taille des pierres et l'estimation préliminaire de leur revenu moyen. A noter que la valeur moyenne d'une pierre dépend de l'importance des pierres de qualité industrielle, ce qui montre qu'une forte concentration de pierres de grande taille ne garantit pas la viabilité économique d'un gisement.

Le second cas d'étude est un autre exemple de gisement kimberlitique de faible concentration. Les échantillons sont regroupés en deux domaines, en fonction de leur concentration en diamants. Dans chaque domaine ainsi délimité, il est possible d'estimer la granulométrie des pierres (en s'appuyant sur les macroéchantillons dans le domaine de faible concentration).

Overview

Two more case studies are presented in this chapter.

The first case study is concerned with a deposit comprising two domains with significantly different levels of kimberlite contamination. Micro- and macrodiamond data are obtained from different sampling programs.

Diamond size and concentration modelling is based on <u>uncontaminated</u> kimberlite. An average contamination factor for each domain is determined from meter-by-meter measurements of contamination in drill core from ALL holes drilled into the deposit. Diamond concentration by domain is subsequently obtained by application of the domain contamination factor.

Macrodiamonds from bulk sampling are available for confirmation of microdiamond size distribution modelling and preliminary revenue estimation. Sensitivity of average diamond value to the presence of low valued industrial stones is demonstrated, showing that a body is not only dependent on high diamond concentration or a coarse diamond size distribution to be economically viable.

The second case study is another illustration of a low concentration kimberlite. This is an illustration of the complications caused by a lack of essential geological information. Subsamples are grouped into two domains on the basis of diamond concentration. Even with low diamond concentration it is possible to obtain a diamond size distribution model, but in this case with the help of macrodiamonds from bulk sampling.

Low diamond concentration accompanied by erratic subsample stone counts prompted an attempt to reproduce sample concentrations by means of simulation. Low grade sampling results are reproduced by assuming that subsample concentration is distributed according to a Poisson variable. For high grade subsamples a longer tail distribution is required to reproduce values similar to actual subsample concentrations.

5.1 Case Study 3

5.1.1 Project background

The deposit is a kimberlite pipe composed of two litho-facies, Hypabyssal Kimberlite (KH) and Kimberlite Breccia (KB). Geologists reported that the two facies differ mainly with respect to their degree of dilution by non-kimberlitic material. The approach in the evaluation exercise was to determine diamond content in uncontaminated kimberlite and the level of kimberlite contamination for each domain. With diamond content estimated in uncontaminated kimberlite it would be possible to apply a domain contamination factor to obtain diamond content.

Diamond grade estimates are based on a combination of macro- and micro- diamond recoveries from bulk samples and drill cores. Sampling was aimed at obtaining a global resource estimate at 'Inferred' level. The implication is that grade continuity may be assumed on the basis of diamond content sampling results and that eventual economic extraction potential must be reasonable. [23]

5.1.2 Sampling

Diamond drilling was used to collect core for geological modelling and microdiamond sampling. A total of 23 holes were drilled to expose contacts between domains within the pipe and between the pipe and wall rock to facilitate geological modelling.

Initial sampling from domain KH comprised of composite material from core, excluding all visible dilution and is denoted as sample type Core-C in Table 5-1. Samples were selected in the form of continuous 8kg core sections with the aim of obtaining material from every 50x50x50m block in the deposit. Treatment took place by means of caustic fusion to recover diamonds above 0.075mm.

Bulk samples were excavated from pits from four distinct surface locations within the pipe perimeter and were individually treated for recovery of diamonds above 1mm.

Material was taken from each bulk sample for microdiamond treatment. Small subsamples were collected from each of these and sent to a different laboratory to serve as sampling audit. The author was not involved with the design of the sampling program.

5.1.2.1 Microdiamond Sampling

Material for microdiamond recovery was collected from drill cores (1.3t) and complemented with material selected from bulk samples (242kg). Small subsamples were selected from the selected bulk sampling material and sent to a different laboratory to be treated for audit purposes. Recovery took place by means of caustic fusion.

Recovery by sample type and domain per subsample are summarised in Table 5-1 in terms of stones above 0.075 and 0.150mm.

[23] European Code for reporting of Mineral Exploration results, Mineral Resources and Mineral Reserves.

Table 5-1 : Summary of microdiamond recoveries

Subsample batch	Sample type	Kimberlite domain	Sample Weight kg	Stones +0.075mm	Stones / 25kg +0.075mm	Stones +0.150mm	Stones / 25kg +0.150mm
KX-1-3	Core - C	KH	70	115	41	46	16
KX-1-1	Core - C	KH	200	490	61	177	22
KX-1-4	Core - C	KH	135	345	64	121	22
KX-1-6a	Core - I	KH	165	250	38	88	13
KX-1-7a	Core - I	KH	165	270	41	127	19
		Sub Total KH	735	1,470	50	559	19
KX-1-8a	Bulk 1	KH	50	215	108	80	40
KX-1-8b	Bulk 2	KH	40	65	41	34	21
KX-1-8c	Bulk 3	KH	45	85	47	45	25
KX-1-8d	Bulk 4	KH	45	127	71	55	31
		Sub Total BS from KH	180	492	68	214	30
KX-1-9a	Audit B1	KH	16	29	45	19	30
KX-1-9b	Audit B2	KH	16	29	45	17	27
KX-1-9c	Audit B3	KH	16	35	55	23	36
KX-1-9d	Audit B4	KH	16	16	25	13	20
		Sub Total KH audit	64	109	43	72	28
		Total KH	979	2,071	53	845	22
KX-1-2	Core - C	KB	95	45	12	24	6
KX-1-5	Core - C	KB	270	50	5	30	3
KX-1-6b	Core - I	KB	150	30	5	9	2
KX-1-7b	Core - I	KB	30	5	4	2	2
		Total KB	545	130	6	65	3
		Totals	1,524	2,201	36	910	15

Subsamples from domain KH were uncontaminated, while high levels of contamination were reported, but not measured in material from domain KB, as is evident from the stone concentrations shown in Table 5-1. For this reason analysis was performed on sampling results from domain KH.

5.1.2.2 Macrodiamond sampling

Bulk sampling was carried out to recover macrodiamonds for diamond valuation purposes. A total of 920 dry tonnes of material was treated and 7,041 diamonds with total weight of 670 carats were recovered at a grade of 0.74 carats per tonne.

Final recovery results are shown in Table 5-2.

The bulk sample comprised Hypabyssal Kimberlite (KH) material, reportedly containing minimum contamination.

One 13.9 carat and 12 stones in the +2 carat size category were recovered. Stones were sieved down to +7 diamond sieve, with more than 5,000 stones below DTC +7 diamond sieve.

Table 5-2 : Summary of bulk sample recovery (920 tonnes, 0.74cts/tonne)

Size class	No of stones	Weight carats	Average stone weight (carats)
+10.8	1	13.90	13.90
+2 Carats	12	38.70	3.23
+21	0	0.00	N/A
+19	6	8.60	1.4333
+17	7	9.15	1.3071
+15	10	10.25	1.0250
+14	45	38.05	0.8456
+11	340	135.35	0.3981
+9	540	104.00	0.1926
+7	645	78.20	0.1212
-7	5435	233.80	0.0430
	7041	670.00	0.0952

5.1.2.3 Kimberlite contamination

Contamination measurements form an essential part of diamond concentration information. All available drilling cores that intersected the pipe were examined for non-kimberlitic inclusions in order to quantify contamination by domain.

Average contamination per domain is summarised in Table 5-3.

Table 5-3 : Summary of % waste by domain

Domain	Core meters logged	Percent Waste
KB	740	60
KH	2253	20
	2993	

5.1.3 Diamond content estimation

The resource was estimated on the basis of microdiamond sampling, bulk sampling and a meter-by-meter assessment of dilution observed in drill core.

Analysis was conducted with the aim of establishing diamond grade in kimberlite from domain KH, concluding with application of a contamination factor as assessed from drill core, by domain.

5.1.3.1 Diamond size

Size distribution plots for all the batches of sampling material are shown in Figure 5-1.

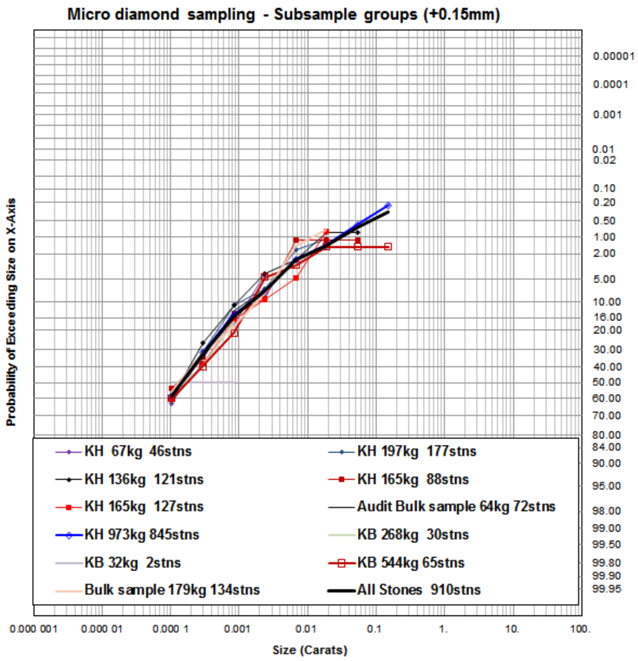


Figure 5-1 : LP-graphs for all subsample groups

The distribution curves appear similar and, as expected, more variability is seen in size distribution curves based on smaller groups of subsamples. Two issues are important with respect to diamond size. The first is whether domains KB and KH have similar size distributions. The second is whether the two laboratories deliver similar results, authenticating the results from the laboratory responsible for diamond recovery. Figure 5-2 shows a comparison between size distributions for diamonds from KH and KB domains and for diamonds recovered at the sample- and audit laboratories.

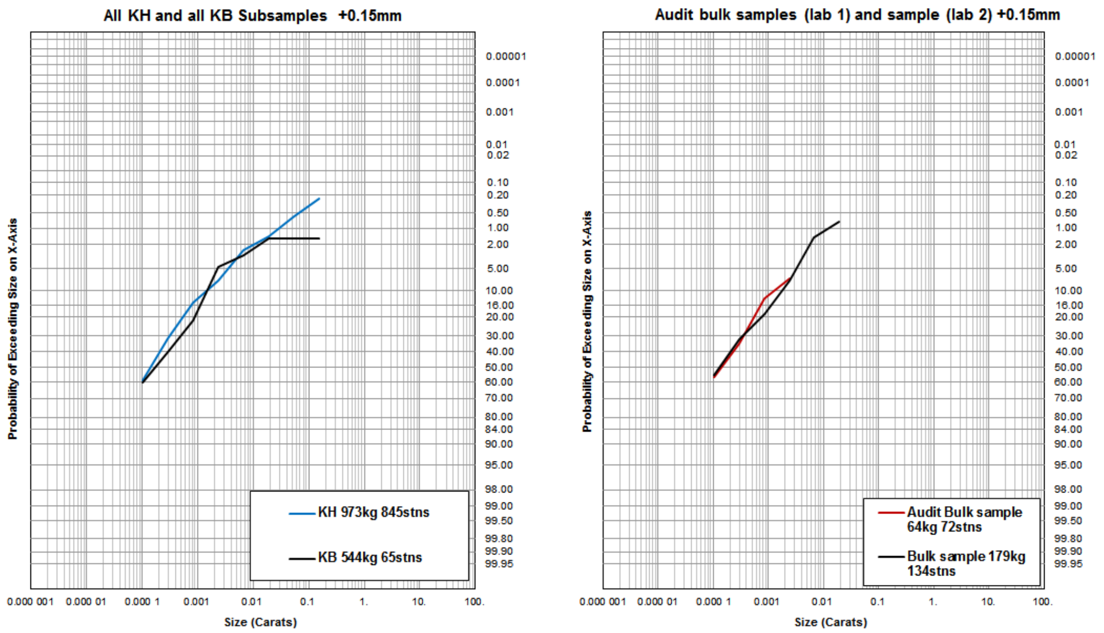


Figure 5-2: Diamond size distribution comparison between domains KH and KB and between sample- and audit laboratories

The number of stones recovered from domain KB would normally not be sufficient for high confidence size modelling, but in this case it was suitable for comparison with recovery from domain KH.

Result of the comparison confirms the idea of one size distribution for both domains. The size plot based on the low number of stones (65) from Kimberlite Breccia shows more variability as expected, but overall it seems as if the two sets of data imply the same diamond size distribution.

The audit laboratory recovered relatively fewer stones below 0.150mm compared with the sampling laboratory, but both labs seem to be erratic in this regard. Only stones above 0.150mm were therefore used in the comparison. The absence of larger stones in the audit sample is due to its small size.

Based on the small amount of data it could at best only be concluded that there does not seem to be reason to suspect inefficiencies in diamond recovery at the sampling laboratory. If the material collected from the bulk samples was split equally for treatment at the sampling and audit laboratories this would have been a more meaningful part of the exercise.

Data for domain KH was subsequently used to obtain the two-parameter lognormal parameters representing the diamond size distribution for the deposit.

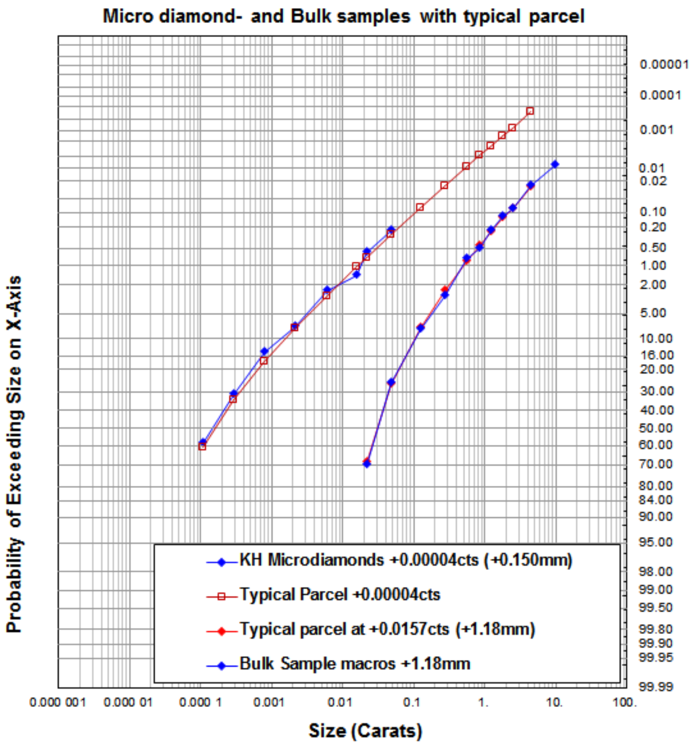


Figure 5-3 : LP-plots showing diamond size distributions based on microdiamonds and bulk sample macrodiamonds. The two curves on the left represent microdiamonds at +0.150mm, while bulk sampling and typical parcel at +1.18mm are represented by the shorter curves on the right. Sampling data is represented by the blue curves. (Bulk sample macrodiamonds were also sieved to +1.18mm)

The mean and standard deviation of the fitted lognormal distribution are 0.000364 and 0.0160 respectively. A typical diamond parcel generated on the basis of the size distribution parameters is plotted with the microdiamond sample results.

Bulk sampling macrodiamond recovery was introduced by adding macro class concentrations to the LP-graph, as shown in Figure 5-3. Thus, the typical parcel was simultaneously compared with microdiamond sampling results at +0.15mm and bulk sampling macrodiamonds at +1.18mm bottom cut-off levels. This typical parcel was based only on microdiamond information. Bulk sampling results were introduced as a check on the validity of size and concentration characteristics derived from microdiamond sampling.

Correspondence between typical parcel and each of the two sets of samples indicates that the diamond size distribution model accurately reflects the overall size distribution of the diamond assortment in the deposit.

5.1.3.2 Diamond content

Diamond content was determined by a combination of the distribution of diamond size and diamond concentration within the deposit. Sample diamond concentration for domain KH is 22 stones per 25kg above 0.150mm, using core and bulk sample microdiamond sampling results (Table 5-1).

A typical diamond parcel was generated by simulating 2million x 25kg microdiamond subsamples. Stone counts were drawn from a Poisson distribution with mean of 22 in accordance with the mean stone concentration for KH microdiamond samples. The size of each simulated stone was drawn in accordance with the 2-parameter lognormal distribution obtained in section 5.1.3.1.

LC-graphs for samples and typical parcel are plotted in Figure 5-4.

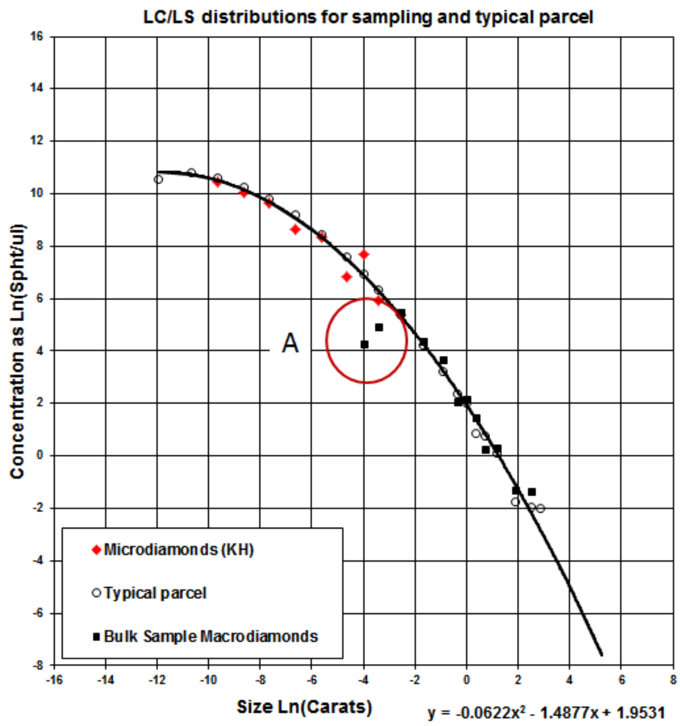


Figure 5-4: LC-curves showing the distribution of diamond concentration for domain KH, indicating close correspondence between sampling and simulated typical parcel.

The red markers represent KH microdiamonds and the black squares reflect macrodiamonds from bulk sampling. The two points in the circle (A) indicate size classes affected by bottom cut-off recovery losses. The close correspondence between the plots for the two sets of samples and the typical parcel curve indicate coherence between micro- and macrodiamonds with respect to diamond size and concentration.

The equation of the LC-curve is $Y = -0.0622X^2 - 1.4877X + 1.9531$ where X represents diamond size in terms of log (carats) and Y is diamond concentration in terms of log stones per 100tonnes per unit size interval. Expected in situ diamond content per size class is calculated by means of this equation.

Alignment factors were calculated from the difference between sample and modelled class concentration in the two bottom size classes. The factors were used to approximate a production grade and size distribution to be used for average recoverable diamond value and revenue estimation. For +1.18mm recovery the factors are 0.1 and 0.7 respectively for size classes +0.85 and +1.18mm as shown in Table 5-4.

Calculations are displayed in Table 5-4 for the full size range in size classes from 0.075mm to 300 carats. The column on the right lists grade in carats per tonne for diamond recovery at +1.18mm. The final column in the table reflects diamond grade with size as depicted in the LC-model in Figure 5-4.

Table 5-4: Results of diamond content modelling. Estimated grade at +1.18mm amounts to approximately 0.69 carats/ton derived from the total in the last column of the table, subject to the +1.18mm bottom cut-off alignment factors shown in the table.

Diamond Sieve	Class Mid-Point	Ln(stones/100t/ui)	Stones/100t/ui	Carats/ton	+1.18mm factor	Carats / ton +1.18mm
150-300cts	193.443	-7.6038	0.0005	0.0005	1	0.000
60-150cts	94.647	-6.1039	0.0022	0.0019	1	0.002
45-60cts	51.759	-4.8871	0.0075	0.0011	1	0.001
30-45cts	36.538	-4.2056	0.0149	0.0022	1	0.002
20-30cts	24.291	-3.4258	0.0325	0.0032	1	0.003
15-20cts	17.118	-2.7739	0.0624	0.0031	1	0.003
10-15cts	12.031	-2.1324	0.1186	0.0059	1	0.006
5-10cts	6.507	-1.0515	0.3494	0.0185	1	0.019
2.5-4cts	3.264	0.1063	1.1122	0.0205	1	0.021
2-2.5cts	2.075	0.8341	2.3028	0.0163	1	0.016
5-6grn	1.469	1.3718	3.9426	0.0203	1	0.020
4grn	1.027	1.9137	6.7781	0.0255	1	0.025
3grn	0.685	2.5060	12.2564	0.0372	1	0.037
2grn	0.390	3.2975	27.0460	0.0722	1	0.072
1grn	0.187	4.2736	71.7822	0.1059	1	0.106
-11	0.078	5.3450	209.56	0.1567	1	0.157
-6	0.032	6.3232	557.35	0.1434	1	0.143
+1180	0.018	6.8990	991.30	0.0603	0.7	0.042
+ 850	0.010	7.5194	1843.42	0.1733	0.1	0.017
+ 600	0.004	8.3582	4264.98	0.1530		0.693
+ 425	0.001	9.0835	8808.99	0.1162		
+ 300	0.000	9.6852	16078.6	0.0781		69cpht
+ 212	0.000	10.1620	25900.4	0.0460		
+ 150	0.000	10.5173	36948.9	0.0245		
+ 106	0.000	10.7462	46450.9	0.0110		
+ 75	0.000	10.8488	51469.9	0.0051		

5.1.3.3 Results

Diamond grade calculated in the previous section reflects diamond grade in domain KH where subsamples are composed of uncontaminated kimberlite. Estimated recoverable diamond grade by domain was calculated by applying contamination factors shown in Table 5-3, namely 20% for domain KH and 60% for domain KB.

Results are shown in Table 5-5.

Table 5-5: Recoverable Grade Estimates

Domain	Waste%	Uncontaminated Grade (cts/100t)		Recoverable Grade (cts/100t)	
		+1mm	+1.18mm	+1mm	+1.18mm
KH	20%	81	69	65	55
KB	60%	81	69	32	28

The accuracy of these grades relies on the accuracy of the waste determinations and the alignment factors. The latter can only be established more accurately once the type of treatment and recovery process is fixed. Waste determination can be enhanced if and when further drilling takes place to improve pipe geology and geometry, but the metre-by-metre measurement on available core must be reasonably representative of dilution in the two domains.

The function of bulk sampling was to confirm the diamond size distribution derived from microdiamonds and to provide macrodiamonds for valuation and revenue estimation. Moreover, observation of a single bulk sample grade being in line with the grade as suggested by a combination of many microdiamond samples from the same domain (KH) could be indicative of a high degree of continuity in diamond content.

5.1.3.4 Diamond Value Estimation

Approach

Macrodiamonds recovered from bulk sampling were valued by size class and results were used to determine average diamond value per size class. Combined with the associated diamond content by size class the overall average diamond value was calculated. This is the average value to be expected from any size-representative diamond parcel from the deposit.

Although the bulk sample parcel may not be fully size representative, the focus is first to determine a value model showing average diamond value with diamond size. Average diamond value increases with increased average size and by comparing sample values with corresponding values for known kimberlites, by size class, average values can be inferred for less populated size classes.

Once diamond value with size is modelled, average diamond value for the domain is determined by combining value and diamond content by size class. Total Dollar value divided by total carat weight provides average value in Dollar per carat.

Data

Bulk sample diamonds valuation results are shown in Table 5-6.

Diamonds available at the time of valuation were cleaned and valued in the size categories shown and split into gem and industrial quality.

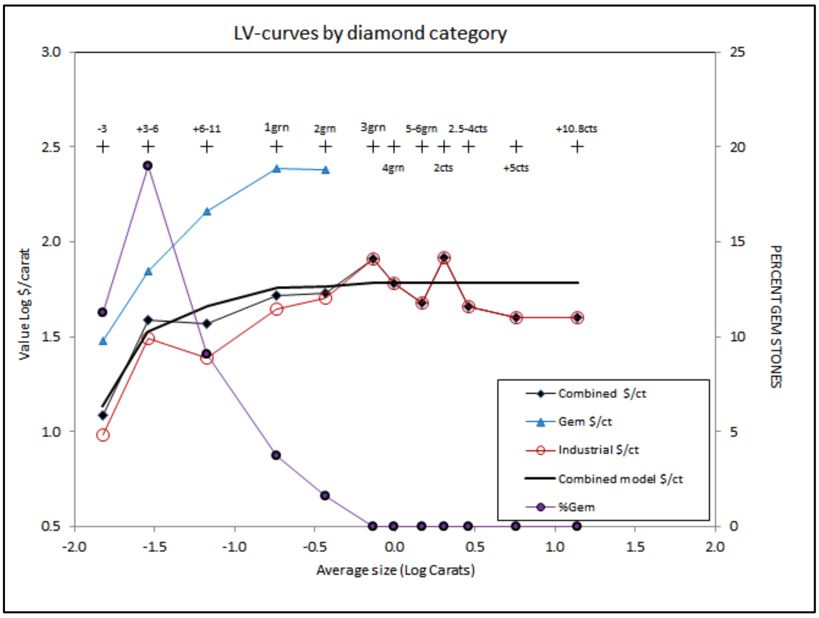
Table 5-6: Valuation summary for macrodiamonds recovered from bulk sampling. (At the time of valuation the complete parcel was not available.)

Size class	Carats Gem	Average Gem ($/carat)	Carats Industrial	Average Industrial ($/carat)	Carats Total	Average $/carat
+10.80	0		14	40	14	40
+ 5 Carats	0		12	40	12	40
2.5 - 4 Carats	0		20	47	20	47
2 Carats	0		8	88	8	88
5 - 6 Grainers	0		21	48	21	48
4 Grainer	0		30	60	30	60
3 Grainer	0		23	83	23	83
2 Grainer	2	180	90	52	92	55
1 Grainer	4	240	105	44	109	51
-11 + 6	15	147	130	25	145	37
-6 + 3	6	68	24	31	30	39
-3	1	26	3	8	4	11
Total	28	143	480	43	508	48
4 Grainers = 1 carat, 5 Carats = 1gram						

The average value of diamonds in the total parcel is $48. The parcel is composed of 28 carats of gem quality at an average value of $143per carat, with the remaining 480 carats in the Industrial category at an average value of $43 per carat. The large proportion (95%) of Industrial goods has a detrimental effect on the value of the parcel.

Value model

The value distribution for the two diamond categories were modelled individually and combined in their parcel size class proportions. Individual class values and the modelled LV-curve are shown in Figure 5-5.



Gem values are depicted in blue.

No gem stone larger than 0.5 carats (2-grainer) is present in the parcel.

Industrial diamond values are depicted in red.

The combined average and Industrial values are similar due to the small proportion Gem stones present.

Figure 5-5: Diamond log-value with size and quality

The percentage Gem stones assumed and observed are depicted by the purple line with values shown on the secondary axis on the right side of the graph.

The proportion of Gem stones is the main element that determines average value and with the information at hand there is little else that can be done about value modelling. The value of larger industrial stones is important, but the parcel does not warrant an increase in value for industrial diamonds larger than 1 carat. It is possible that the deposit contains high valued larger Gem stones, but the data does not support the idea.

Summary

A combination of diamond value and size models yields estimates for recoverable diamond grade and value at +1mm and +1.18mm as shown in Table 5-7.

Table 5-7: Recoverable grade and diamond value estimates

FACIES	Recoverable Grade (carats/100t) not rounded		Dollar per Carat		Dollar per Tonne (not rounded)	
	+1mm	+1.18mm	+1mm	+1.18mm	+1mm	+1.18mm
KH	65	55	49	54	31	30
KB	32	28	49	54	16	15

There is almost no difference in estimated revenue per ton between +1 and +1.18mm recovery as the increase in Dollar per carat is offset by the decrease in grade.

5.1.4 Conclusion

5.1.4.1 Diamond grade

- Diamond concentration is based on microdiamond sample stone counts. The number of samples and the fact that these samples were collected from drill core at depth as well as the consistency of stone counts means that the estimates are not likely to materially change if more information becomes available.
- Kimberlite dilution for domain KH is based on almost 3,000 meters of core and the assumed waste percentage of 20% seems reasonable.
- The 60% waste content for domain KB seems reasonable as well, considering the low microdiamond sample stone counts observed in domain KB.
- The diamond size distribution is based on more than 800 microdiamonds and is confirmed by macrodiamonds from the bulk sample, providing further confidence in diamond content estimates.
- Calculation of confidence limits for diamond grade and spatial estimation of kimberlite dilution are not demonstrated in this case study.

5.1.4.2 Diamond value

- If the percentages gem quality stones above 2 carats turn out the same as the percentage observed in the smaller size classes, average diamond value at +1mm recovery could be higher.
- If the average value of Industrial quality stones keeps increasing up to the 5 carat size category then the average Dollar per carat value at +1mm recovery could be higher.
- A coarser diamond size distribution is unlikely, ruling out a consequential higher average Dollar per carat value.

It seems unlikely for this deposit to have lower average diamond values than those suggested by the bulk sample.

It is concluded that the values and grades in Table 5-7 are the best estimates for this deposit based on current sampling information.

If all the sampling material represents the deposit appropriately, then it is almost certain that average diamond value will be around 49 Dollars per carat for diamond recovery at a bottom cut-off of +1mm.

The low frequency of gem quality stones with increased diamond size remains to be confirmed.

This case study is an example of a project that will have to be sampled to a point where it will become clear whether or not the project has to be abandoned in view of low diamond values. More bulk sampling is required.

The study also illustrates a way around the application of extreme value statistics to obtain an estimate for average diamond value in a deposit.

5.2 Case Study 4

5.2.1 Project background

This is an example of a kimberlite with low microdiamond concentration and with sampling information not accompanied by any geological information.[24] The case is useful as demonstration of application of basic microdiamond estimation techniques and is accompanied by an assessment of the sampling program.

Sampling data from the kimberlite is assumed to represent two geological domains containing low grade and high grade kimberlite. Subsamples and samples without lithological coding form the data base and are allocated to domains strictly on the basis of their stone counts.

A macrodiamond parcel recovered by means of bulk sampling is available for size distribution modelling. Diamonds have been valued and, combined with provisional diamond content estimates allow an assessment of average diamond value and revenue. Analysis is based on micro- and macrodiamond recoveries, with macrodiamonds playing an essential part due to low microdiamond counts.

5.2.2 Sampling and estimation of diamond content

5.2.2.1 Microdiamond sampling

Microdiamond samples were collected from drill core and shaft material. Core lengths weighing approximately 64kg of material were selected from drilling cores and split into 8kg subsamples for Caustic Fusion treatment.

A summary of microdiamond sampling results broken down in mm size classes is given in Table 5-8.

Table 5-8 : Summary of microdiamond sampling results

Domain	High	Low	Low	Low	Low	High	Low	Low	Low	High	Low	Low total	High Total	Total
Dry Wt (kg)	220	221	225	200	191	270	213	240	240	155	133	1663	645	2308
Sample	D1	D2	D3	D4	D5	D6	D7	SM1	SM2	SM3	SM4			
4.75mm	0	0	0	0	0	0	0	0	0	1	0	0	1	1
3.35mm	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.36mm	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.7mm	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.18mm	0	1	0	0	0	1	0	0	0	1	0	1	2	3
0.85mm	0	0	0	0	1	0	0	0	0	3	0	1	3	4
0.6mm	2	1	1	0	0	10	2	2	4	3	1	11	15	26
0.425mm	4	0	0	0	0	0	1	1	1	0	0	3	4	7
0.3mm	4	2	3	0	0	5	1	6	4	3	1	17	12	29
0.212mm	5	0	6	0	0	10	1	7	3	9	1	18	24	42
0.15mm	12	3	6	2	0	18	6	3	14	4	3	37	34	71
0.106mm	25	1	13	4	1	18	5	5	22	18	5	56	61	117
0.074mm	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stones	52	8	29	6	2	62	16	24	48	42	11	144	156	300
Stns/100kg +0.106mm	23.6	3.6	12.9	3.0	1.0	23.0	7.5	10.0	20.0	27.1	8.3	8.7	24.2	13.0
Stns/100kg +0.150mm	12.3	3.2	7.1	1.0	0.5	16.3	5.2	7.9	10.8	15.5	4.5	5.3	14.7	7.9

[24] The data in its current form was provided without any prior involvement by the author.

Diamond recovery took place at +0.106mm (0.000016cts) bottom cut-off. The locations of the sample cores were recorded, but subsamples were selected irrespective of their positions along the core, ruling out the possibility of applying spatial analysis. Core samples were collected from surface down to depths below 250m.

Subsamples with stone concentration exceeding 10 stones/100kg (+0.150mm) were grouped together as high grade kimberlite. Sampling from low grade kimberlite amounted to 1,663kg and yielded 144 stones, while High grade kimberlite amounted to 645kg and yielded 156 stones.

Microdiamond recoveries were generally low with few exceptions. A combined sampling average diamond concentration of 13 stones per 100kg was calculated, with low grade average at 9 and high grade average at 24 stones/100kg.

Table 5-8 gives a breakdown of stone frequencies in mm sieves from 0.106mm to 4.75mm as supplied by the treatment laboratory.

5.2.2.2 Macrodiamond Sampling

Bulk samples were excavated from surface trenches and from a single shaft going down to a depth of 130m. Diamonds were recovered at a bottom cut-off size of 1mm and sampling yielded 1,480 carats from 5,660 tonnes of material.

A size breakdown of stone frequencies is shown in terms of DTC size classes. Totals are for +3 diamond sieve recoveries to eliminate recovery inconsistencies in the -3 size class.

Data is summarised in Table 5-9.

Table 5-9 : Summary of macrodiamond recoveries from bulk sampling

Source	Trenches				Shaft				All
Sample	T1	T2	T3	T1+T2+T3	S1	S2	S1+S2	S3	T+S
Tonnes	1,831	2,328	823	4,982	226	235	461	218	5,660
+ 5 ct	3	6	1	10	0	0	0	2	12
4 ct	1	6	1	8	1	1	2	1	11
3 ct	7	9	3	19	1	1	2	2	23
10 gr	4	4	1	9	1	1	2	1	12
8 gr	17	20	6	43	2	2	4	5	52
6/5 gr	29	31	10	70	4	4	8	8	86
4 gr	24	32	9	65	4	4	8	8	81
3 gr	40	65	17	122	7	7	14	14	150
+11	145	203	105	453	28	27	55	60	568
+9	215	342	139	696	32	36	68	79	843
+7	224	322	167	713	36	35	71	76	860
+5	662	997	293	1,952	119	120	239	250	2,441
+3	624	872	164	1,660	75	110	185	140	1,985
-3	0	0	48	48	14	29	43	19	110
Stones (+3)	1,995	2,909	916	5,820	310	348	658	646	7,124
Stones / 100t (+3)	109	125	111	117	137	148	143	297	126
Carats (+3)	413	609	180	1202	59	64	124	154	1480
Carats/ 100t (+3)	23	26	22	24	26	27	27	71	26

Most of the sampling was assumed to have come from low grade kimberlite, with the majority from surface trenches.

Judging by diamond recovery from the shaft it appears that one of the shaft samples (S3) intersected kimberlite containing diamonds at a significantly higher level of concentration.

5.2.2.3 Diamond Size Distribution

Microdiamond results provide information about the distribution of diamond size in the finer diamond size range.

Not many stones were recovered from low grade material and the amount of sampling from the high grade domain was too little to compensate for this. A comparison was made to see if it would be possible to combine the data for size distribution analysis.

LP-graphs for the two domains in Figure 5-6 show a slight difference in size distribution.

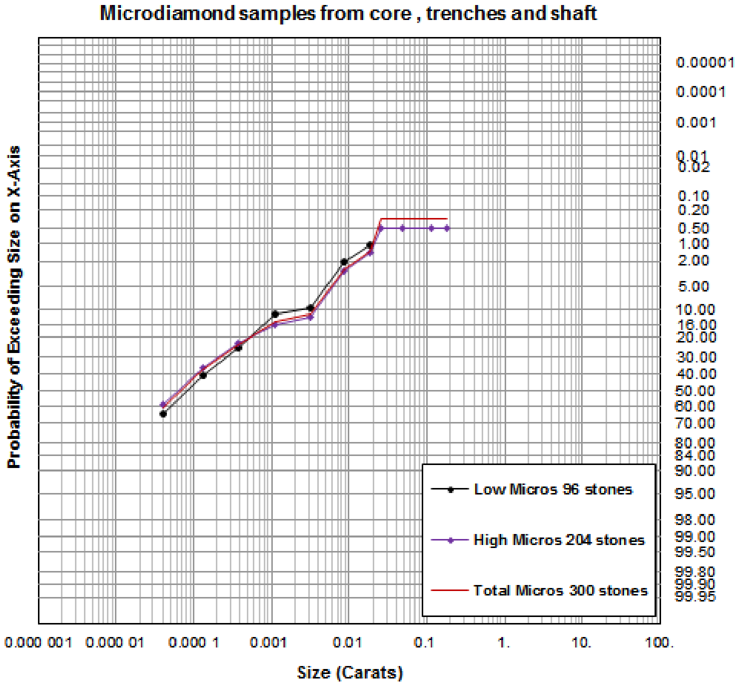


Figure 5-6 : LP-graphs for microdiamonds.

The difference between the graphs is not consistent and is most likely due to the low stone counts. Separate size models were therefore not warranted. Substantial additional microdiamond sampling would be required to confirm this. However, bulk sampling results were available to provide information from the coarser size fraction.

Size distributions for bulk samples are compared in Figure 5-7.

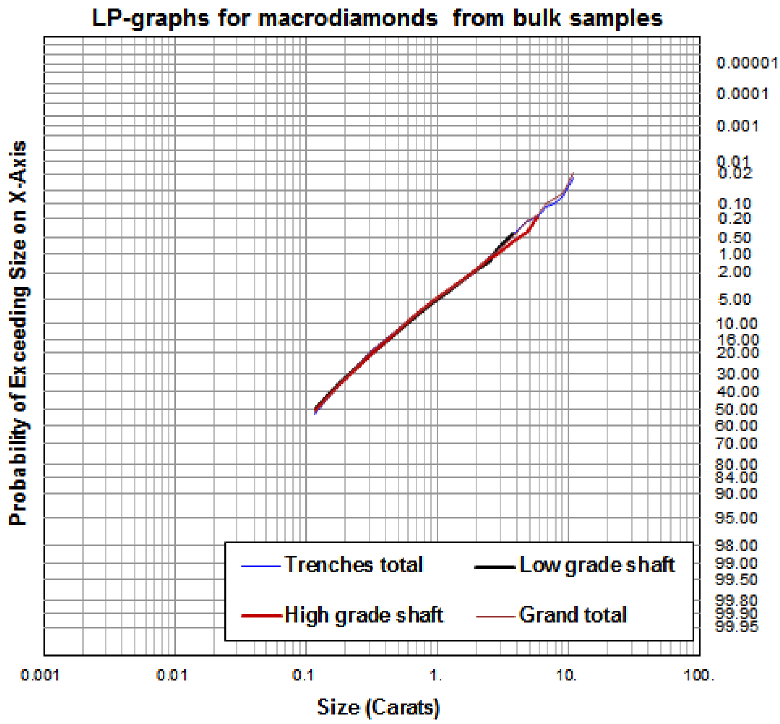


Figure 5-7 : LP- graphs for combined bulk samples showing similar size distributions for low- and high grade shaft samples and trench samples.

The graphs do not indicate a difference in diamond size distribution between trenches and shaft samples or between high and low grade kimberlite, implying that the distribution of diamond size is the same for both kimberlite types.

Diamond concentration would therefore account for differences in diamond content between domains in the pipe.

Size modelling was based on a combination of micro and macrodiamond results.

The parameters of a lognormal distribution were obtained by means of iterative simulation, based on microdiamond and bulk sampling data.

The final set of graphs is presented in Figure 5-8, showing sampling data and typical parcel. The graphs depict typical parcel with sampling at bottom cut-off sizes of +0.106mm for microdiamonds and +3 diamond sieve for bulk sampling.

The size distribution for diamonds in the kimberlite follows a 2-parameter lognormal distribution with mean and standard deviation equal to 0.001598 and 0.0928 respectively.

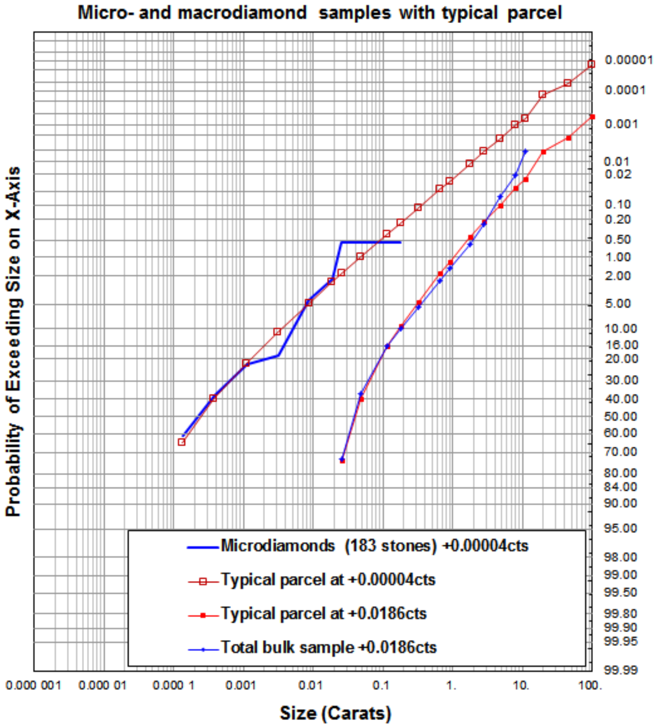


Figure 5-8 : Diamond size distribution model based on microdiamonds and bulk sampling macrodiamonds. High and low grade domain samples are combined. Typical parcel is truncated at +0.150mm (0.00004cts) to compare with micros (left) and at +1DTC (0.0186cts) to compare with macros (right).

The two graphs on the left represent actual microdiamonds and typical parcel with corresponding bottom truncation at 0.00004cts. Bulk sampling and typical parcel coinciding at corresponding bottom truncation levels at 0.0186cts are shown on the right. In accordance with the discussion in section 3.2.4 the comparison of typical parcel and bulk sample size class concentrations in the lower four macrodiamond size classes suggests alignment factors of 0.9, 0.6,0.3 and 0.022 for DTC sieves +7, +5 , +3 and -3.

Ideally the correspondence between the two microdiamond curves on the left should be better, but with low microdiamond counts the deviation is not surprising. It nevertheless seems as if the curves belong to the same size distribution.

A common size distribution model for all samples from the pipe implies that differences in diamond content between domains will be determined by diamond concentration.

5.2.2.4 Diamond Grade

As for diamond size all samples were initially combined to obtain an estimate for diamond grade. Combined microdiamond concentration at bottom truncation level of +0.150mm (0.00004cts) is 7.9 stones/100kg.

A typical diamond parcel was simulated with size distributed according to the lognormal distribution modelled for the combined samples and with diamond concentration assumed to be a Poisson variable with mean 7.9 stones per 100kg. The diamond parcel was formed by simulating 200,000 microdiamond subsamples each weighing 100kg.

LC-graphs are shown in Figure 5-9.

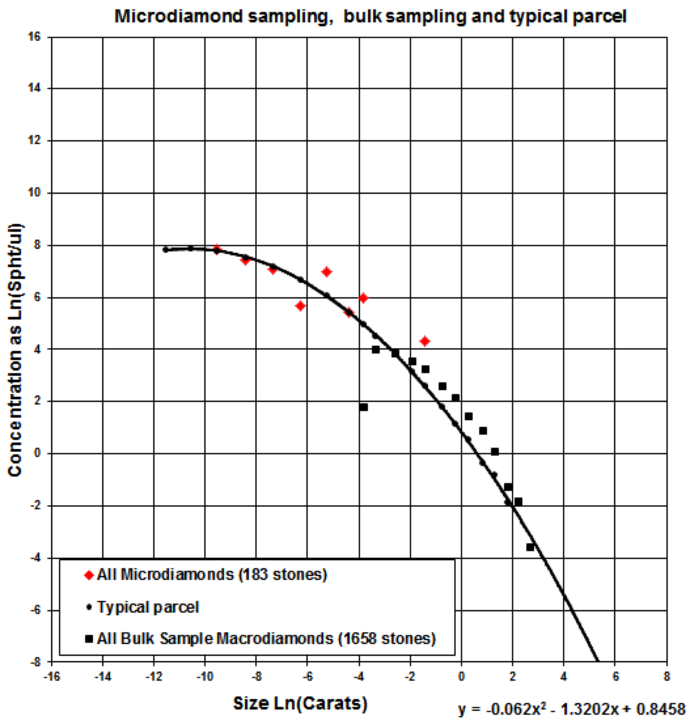


Figure 5-9 : LC-model with microdiamonds and bulk sampling macrodiamonds recovered from sampling material collected from high and low grade domains. Size distribution is based on all sampling data and average diamond concentration is based on microdiamond sampling. Diamond concentration in microdiamond subsamples is assumed to be a Poisson variable with mean 7.9.

Sparseness of microdiamond data is responsible for the erratic distribution of sample values indicated by red markers.

Bulk sampling values indicated by blue markers are distributed above typical parcel. This is a consequence of a difference in the material represented by microdiamond sampling and bulk sampling. Microdiamond sampling possibly includes a higher volume of low grade material, compared with bulk sampling.

Application of the alignment factors from the previous section (5.2.2.3) to the bulk sample recoveries and 'shifting' the microdiamond LC-curve upwards towards the bulk sample points, culminates in a LC-model associated with bulk sampling as shown in Figure 5-10.

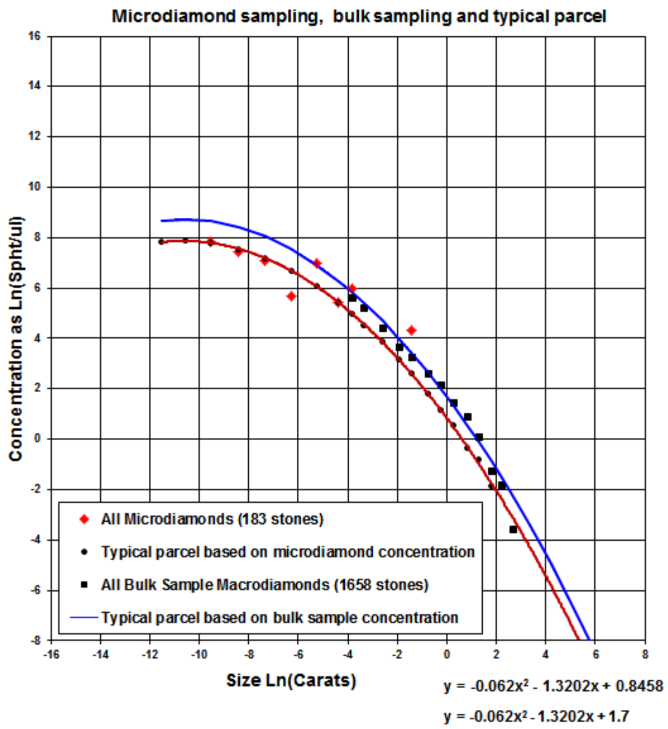


Figure 5-10 : Adjustment of bulk sample recoveries in lower size classes to compensate for recovery losses and shifting the microdiamond LC-curve to intersect bulk sample points leads to a parallel LC-curve for the bulk sample. This indicates that material represented by bulk sampling and microdiamond sampling differs with respect to diamond concentration.

The two LC-graphs represent microdiamonds and bulk sampling macrodiamonds and depict different diamond concentration levels. The parallel lines are indicative of identical size distributions.

It is therefore possible to compare two sampling programs, based on entirely different bottom sample truncation levels, by means of their respective LC-curves. In this case the comparison exposes different levels of diamond concentration in the results for two sampling programs.

Based on the indication that diamonds in all the sampled material seem to have the same size distribution, it is easy to obtain diamond content estimates for domains differing only with respect to diamond concentration.

Diamond content was subsequently estimated for low and high grade microdiamond material as well as for bulk sampling combined and the single high grade bulk sample (S3) shown in Table 5-9.

Comparing microdiamond- and bulk sample recoveries

High grade microdiamond samples were combined and plotted with bulk samples without the high grade shaft sample to compare high grade microdiamond and bulk sampling results.

A typical parcel was simulated based on the overall diamond size distribution fitted in section 5.2.2.3 and assuming microdiamond concentration calculated for the high grade microdiamond samples. 200,000 x 100kg subsamples were simulated with the number of stones per subsample drawn from a Poisson distribution with mean 14.7 and with stone weights allocated according to the combined size distribution model.

The associated typical parcel with micro and macrodiamond samples is shown in Figure 5-11.

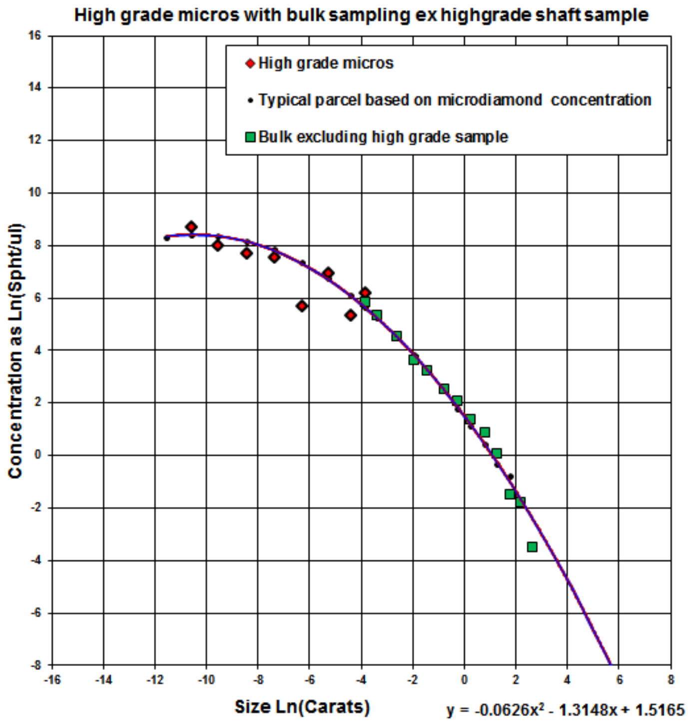


Figure 5-11 : Comparing microdiamond- and bulk sample results. LC-curve shows that high grade microdiamond samples are coherent with respect to bulk sampling results, excluding the one highest grade bulk sample.

Figure 5-11 shows that high grade microdiamonds and the bulk sampling results, excluding the higher grade bulk sample, provide a coherent diamond concentration model, suggesting an average grade of 26cpht.

Grade for material with low microdiamond concentration of 4.4 stones/100kg was estimated at 7cpht and for the high grade bulk sample grade was estimated at 73cpht.

All grade estimates assumed recovery to take place in accordance with the bulk sampling plant.

It seems clear that sampling intersected more than one domain and that grade could vary from 7cpht to 70cpht, but with the majority of sampling having intersected material at an average grade of 26cpht. There is no sense in providing confidence limits on the basis of the sampling information provided.

It is unfortunate that with the amount of sampling already done, there is no geological model for the deposit. It is quite likely that the deposit may contain domains that could be economically viable for mining.

With macrodiamonds available it is possible to make a preliminary estimate of average diamond value.

The greatest need at this stage of the project is to construct a functional geological model.

Therefore the next step in the development of this ore body is to examine available drill cores in order to create a geological model, and to do more drilling for this purpose if necessary.

5.2.3 Sampling assessment

This section examines sampling aspects relating to kimberlite with low diamond concentration based on sampling data for this deposit.

Of the two variables required for diamond content modelling, diamond size and diamond concentration, the major issue with this deposit is its low concentration of microdiamonds.

To develop a resource model for the deposit the main variable of interest is diamond concentration, as sampling so far supports the use of a common size distribution. The statistical nature of diamonds in the deposit is thus examined in order to characterise the behaviour of diamond concentration.

Sample size

The LC-model represents diamond concentration in terms of stones per unit interval per 100 tonnes for all size classes considered in the size breakdown. These values are easily converted to stones per kg per size class followed by inversion (from stones per kg to kg per stone) to the amount of kg per stone per size class. The LC- distribution is thus transformed into a graph giving an indication of average weight of kimberlite (in kg) associated with recovery of a stone in a size class.

The relationship for low grade kimberlite is presented graphically in Figure 5-12.

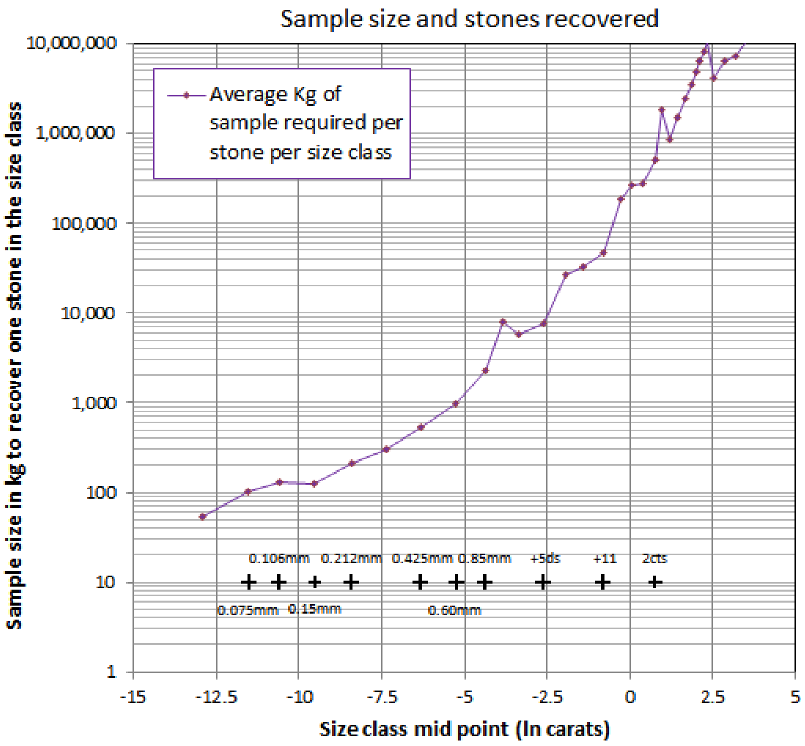


Figure 5-12 : Average amount of low grade kimberlite required for recovery of one stone per size class. Discontinuities in the graph are due to shorter class lengths.

The average stone count for the 1.663 tonne combined microdiamond sample is 8.7 stones per 100kg (+0.106mm). The size breakdown is listed in the 'Low Total' column in Table 5-8.

The graph in Figure 5-12 shows that size classes below 0.60mm require an average of up to 500kg of sample for the recovery of one stone per size class. It is estimated that an average of approximately 2000kg of material is required to recover a stone in the +0.85mm size class.

There is a good chance of recovering stones up to the +0.150mm size class with subsamples of a little more than 100kg from this kimberlite. To recover a stone in the +0.212mm size class an average subsample size double this size is required.

Note this does NOT imply zero probability for the occurrence of larger microdiamonds in subsamples weighing less than 100kg.

Both kimberlite domains display low concentrations of microdiamonds. In this case microdiamond sampling in particular does not provide the usual benefits with respect to diamond content estimation. Microdiamond results were used in a more comparative fashion rather than the usual dominance during modelling procedures. Bulk sampling provides sufficient numbers of macrodiamonds for size modelling, without which uncertainty levels would be high.

The large difference between high and low grade kimberlite requires an accurate and detailed geological model, which will probably require more core drilling. This will provide an opportunity for more microdiamond sampling, which will need to be well planned in view of current knowledge of the nature of diamond content. For instance, if more microdiamond sampling is carried out the 8kg subsamples should be collected as individual sections of core, with the location of each subsample recorded. This is what should have been done from the onset of microdiamond sampling.

In spite of the low stone frequencies from microdiamond sampling, it will be possible to design a cost effective microdiamond sampling plan for further evaluation of this kimberlite. With diamond size distributions known from bulk sampling, the only aspect that needs to be determined throughout the body is diamond concentration.

Uncertainty with respect to this variable can be reduced by increasing the number of microdiamond samples or increasing the size of a subsample (see also [57]). Each subsample will provide diamond concentration information, whether it contains diamonds or not, but the correct sampling protocol must be followed.

For instance, in a situation such as this it is advisable that core sections are sampled and treated in consecutive 8kg sections. This way it will be possible to combine (consecutive) sections to form larger support samples, as shown in the case study discussed in Section 4.1.

The effect of increased sample support is illustrated in Figure 5-13.

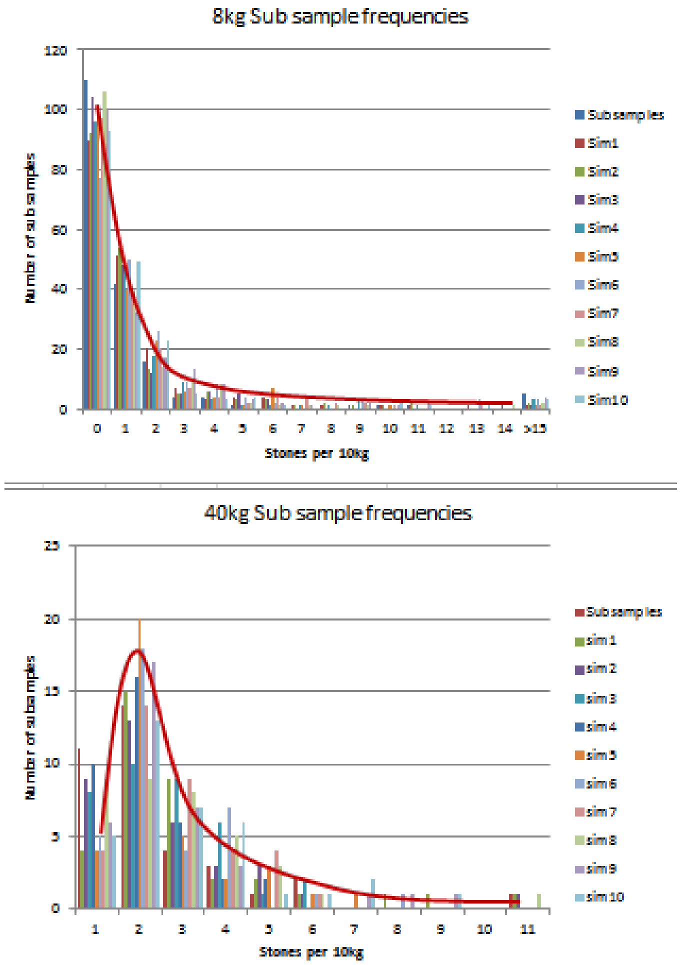


Figure 5-13 : Histograms of stone counts based on different sample size. Top graph displays histogram of 8kg subsamples. Bottom graph shows histogram for 40kg subsample (5 subsamples combined).

The distributional characteristics for 8kg subsamples are in the form of a reversed J-shaped distribution, which can be modelled by Poisson-, Negative Binomial- or Sichel distributions.

When the subsamples are combined into 40kg samples the distributional character is no longer in the form of a reverse J-shaped distribution. Further increase in the number of subsamples being combined will lead to a more symmetric statistical distribution.

Deposit geology will have to play a more important role in the development of this resource. Contamination by non-diamondiferous material could turn out to be an important variable to be measured for diamond content estimation, regardless of the nature of the next sampling stage. If it is found that there is high correlation between diamond concentration and kimberlite contamination then drilling could provide core for measurement of contamination, potentially restricting the amount of microdiamond treatment. At the same time geological logging of the core will provide more information to improve the geological model.

This case study is an example of sampling for diamond content in an environment that does not favour the use of microdiamonds, but where full use of the methodology still provides essential information that would otherwise be obtained at high cost.

6 Case Studies III

Résumé

Le cas d'étude présenté ici est celui d'un gisement multifaciès qui a déjà fait l'objet d'un échantillonnage approfondi, tant du point de vue microéchantillons que macroéchantilons.

Sa fonction est d'illustrer divers aspects de l'estimation des ressources. Elle n'est montrée que sur l'un des principaux faciès identifiés du gisement. Traité comme un tout, ce domaine est découpé en deux sous-domaines pour rendre compte de l'évolution de la granulométrie des pierres en fonction de la profondeur.

La donnée des volumes et des tonnages approximatifs des sous-domaines donnent une idée de leurs dimensions.

Les variables d'intérêt étudiées sont la granulométrie des pierres et leur concentration qui fournissent des estimées du contenu du domaine en diamants.

Moins variable que la teneur en carats, la concentration en pierres est choisie comme variable principale pour cette étude. De valeur extraordinairement élevée, elle permet l'étude de la sensibilité des estimateurs au seuil inférieur de troncature.

Overview

The case study focuses on data from an advanced sampling campaign during which various sampling programs yielded micro- and macrodiamond data from a deposit with multiple litho-facies.

The aim of the study is to illustrate aspects of diamond content estimation in advanced mineral resource sampling. For this purpose it was deemed sufficient to consider only one of the main litho-facies identified in the body. The domain is considered as a whole and broken down into two configurations of sub-domains to cope with possible changes in diamond size distribution with depth. This is similar to a situation where diamond content is required in super blocks[25].

[25] Large irregularly sized blocks assigned grade and value on the basis of sampling data from the block.

Approximate volumes and tonnages are supplied to give an impression of the magnitude of the domain considered.

The case study is focused on diamond size distribution and concentration, culminating in estimates for diamond content.

Higher variability of carat grade as compared with stone grade is observed with depth, which is the reason for using diamond concentration as primary variable in this type of exercise. The domain considered has extraordinary high diamond concentration and the study illustrates the sensitivity of grade and value to bottom truncation.

6.1 Case Study 5

6.1.1 Project background

The deposit comprises several kimberlite types. For the illustration one domain in the form of a vertical kimberlite structure sampled to a depth of 600m is considered.

If a complete diamond content estimation exercise was carried out for this body, each identified domain in the body would be treated according to the methodology discussed in this study.

6.1.2 Sampling

Sampling took place over an extended period and at different stages the data was verified and used in resource estimation studies. Sampling campaigns comprised core- and large diameter percussion drilling with diamond recoveries at +0.075mm and +1mm bottom cut-off.

Microdiamonds were recovered from diamond core and recovery took place above 0.075mm. Samples with an average weight of 20kg were collected from drill core which intersected the kimberlite to a depth of 600m.

Macrodiamonds were recovered from two sampling campaigns. Solid drill core was obtained from diamond drilling at a bit diameter of 100mm. Material was crushed and treated for the recovery of macrodiamonds. The purpose of this program was to obtain a representative diamond parcel from the upper 500m of kimberlite.

Macrodiamonds were also recovered from large diameter percussion drilling (ldd) with the purpose of increasing the size of the diamond parcel for valuation.

Large diameter percussion sampling requires estimation of sample weights which could be unreliable, with detrimental effect on sample diamond grades. This data was therefore only suitable for diamond size and revenue estimation.

With macrodiamond data from core it was possible to check for sampling inconsistencies between micro- and macrodiamonds.

6.1.3 Sampling Data

6.1.3.1 Microdiamonds from core

A detailed microdiamond sampling program yielded 206 subsamples at an average subsample weight of 20kg.

A total of 30,870 stones were recovered from the combined sample weighing 4.2 tons, with 103 stones presenting above +0.85mm square mesh. Treatment took place by means of caustic fusion at bottom cut-off aperture of 0.075mm square mesh.

A size breakdown of diamond recovery is summarised in Table 6-1.

Table 6-1: Summary of microdiamond recoveries at +0.075mm

Weight kg		4,155
No of Samples		206
Average sample weight in kg		20
Diamond sieve (mm)	Class lower limit	Diamonds recovered
4.75	1.3	0
3.35	0.4686	1
2.36	0.1711	7
1.70	0.0662	9
1.18	0.0228	29
0.850	0.008725	61
0.600	0.003119	264
0.425	0.001119	599
0.300	0.000395	1,341
0.212	0.000139	2,558
0.150	0.000049	4,755
0.106	0.000016	8,469
0.075	0.000006	12,777
		30,870
Stones/20kg + .075mm		149
Stones/20kg +0.106mm		87
Stones/20kg + .150mm		46

6.1.3.2 Macrodiamonds from Large diameter core and percussion drilling

100mm Diameter core drilling was employed to recover macrodiamonds above a bottom cut-off aperture of 0.5mm. Macrodiamonds were required to confirm the size distribution model derived from microdiamonds and potentially also for spatial analysis of diamond potential.

Vertical and angled holes were drilled to obtain a spatially representative sample from the deposit and results are shown in Table 6-2.

500mm Diameter percussion drilling was employed to yield a large diamond parcel for valuation purposes. The size of the subsamples varied substantially. Diamonds were recovered above a bottom cut-off aperture of 1mm square mesh.

At the location of each percussion hole an additional 200mm large diameter core hole was drilled to provide geological information for the percussion samples. Core material was treated for diamond recovery and results are summarised in Table 6-2.

Table 6-2 : Summary of macrodiamond sampling results

	100mm LD Core at +0.5mm recovery		**200mm LD Core at +0.5mm recovery**		**500mm percussion drilling results at +1mm * recovery**	
Screen aperture	**Stones**	**Carats**	**Stones**	**Carats**	**Stones**	**Carats**
+4mm	**9**	**9.57**	**6**	**6.81**	**59**	**59.58**
+2mm – 4mm	**207**	**43.07**	**170**	**31.68**	**1,402**	**264.49**
+1mm – 2mm	**1,945**	**53.90**	**1,365**	**38.67**	**11,043**	**319.75**
+0.5mm - 1mm	**6,469**	**28.13**	**5,914**	**25.72**	**4,003**	**32.28**
-0.5mm	**143**	**0.16**	**86**	**0.14**	**137**	**0.16**
TOTAL	**8,773**	**134.82**	**7,541**	**103.02**	**16,644**	**676.26**
Sample weight (kg)	**115,479**		**82,788**		**710,843**	
Cts/ton +1mm		**0.92**		**0.93**		**0.91**
Cts/ton +0.5mm		**1.17**		**1.24**		**0.95***

Results from these vast sampling programs suggested the presence of a high proportion stones below 2mm square mesh. Individual +0.5 and +1mm sample results were meant for spatial analysis of diamond concentration and the combined +1mm recoveries for diamond valuation.

6.1.4 Zonal Diamond Content

6.1.4.1 Uniformity of size distribution

Sampling data was split into depth zones and analysed to check for changes in diamond size distribution with depth. It was reasonable to expect variation in diamond content within the large domain selected for analysis. Smaller subdomains were therefore formed to identify any that might have to be analysed separately because of deviation from a common size distribution. The division was done by depth zone and subdomains are shown in Table 6-3 with their size distributions presented in log probability format in Figure 6-1.

Table 6-3 : Microdiamonds per size class in 48m benches with depth

Depth below sea-level (m)	-32 to -80	-80 to -128	-128 to -176	-176 to -224	-224 to -272	-272 to -320	-320 to -368	-368 to -416	-416 to -464	-464 to -512
Samples	14	27	18	21	23	23	22	21	23	14
Sample kg	275.2	542.7	357.8	418.4	469.2	457.6	448.6	426.7	469.3	289.0
+ 3.35 mm	0	1	0	0	0	0	0	0	0	0
+ 2.36 mm	0	1	1	0	3	1	0	0	1	0
+ 1.70 mm	1	3	0	1	2	0	2	0	0	0
+ 1.18 mm	0	8	4	6	1	3	2	0	5	0
+ 0.85 mm	2	7	4	7	9	8	7	6	9	2
+ 600 µm	22	41	16	30	28	33	30	19	28	17
+ 425 µm	42	91	62	54	69	74	71	42	58	36
+ 300 µm	87	184	100	126	172	150	159	116	155	92
+212 µm	167	344	207	264	278	287	315	240	289	167
+150 µm	339	606	353	460	584	524	570	450	552	317
+106 µm	575	1,101	627	823	966	923	1,046	775	971	662
+ 75 µm	943	1,495	956	1,326	1,510	1,449	1,530	1,112	1,428	1,028
TOTAL	2,178	3,882	2,330	3,097	3,622	3,452	3,732	2,760	3,496	2,321
Stones /20kg +0.106	90	88	77	85	90	88	98	77	88	89
Stones /20kg +0.150	48	47	42	45	49	47	52	41	47	44
Stones /20kg +0.212	23	25	22	23	24	24	26	20	23	22

The kimberlite was subdivided into 48m benches between elevations as shown in the table, with subdomains containing between 14 and 23 subsamples. Combined subsamples weighed between 275kg and 542kg and were large enough for individual zonal diamond content modelling.

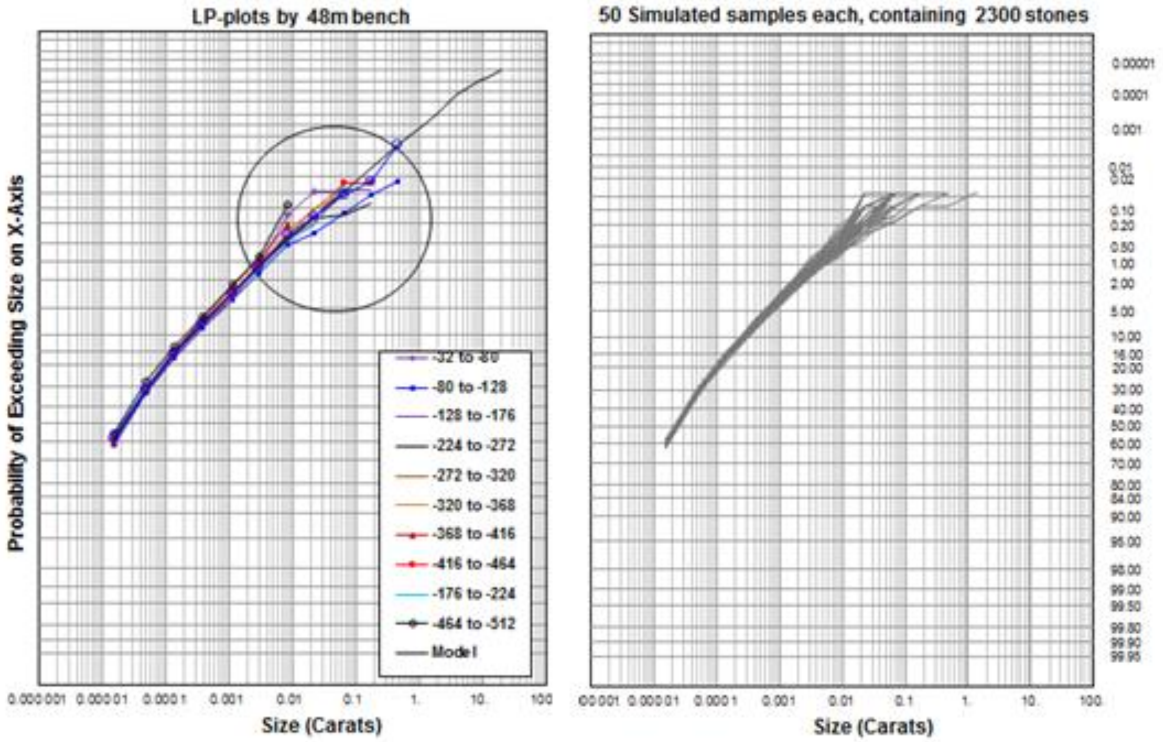


Figure 6-1 : LP-graphs for 48m bench subdomains and for 50 simulated samples.

Size distribution plots indicate similarity between benches with most of the variability circled in the larger size classes as expected. The graph for the deepest bench (-464 to -512m) seems to indicate a slightly finer size distribution. Too many stones were involved to assign the reason for the deviation only to sample variability.

Simulated graphs are shown to illustrate the effect of sample variability, supporting the conclusion that diamonds in the subsamples from the deepest bench seems to have a finer size distribution.

Average diamond size was calculated for diamond recovery at +0.075mm and +0.212mm and are depicted in Figure 6-2. For this purpose the 48m benches were subdivided further to obtain more detail for the graphs.

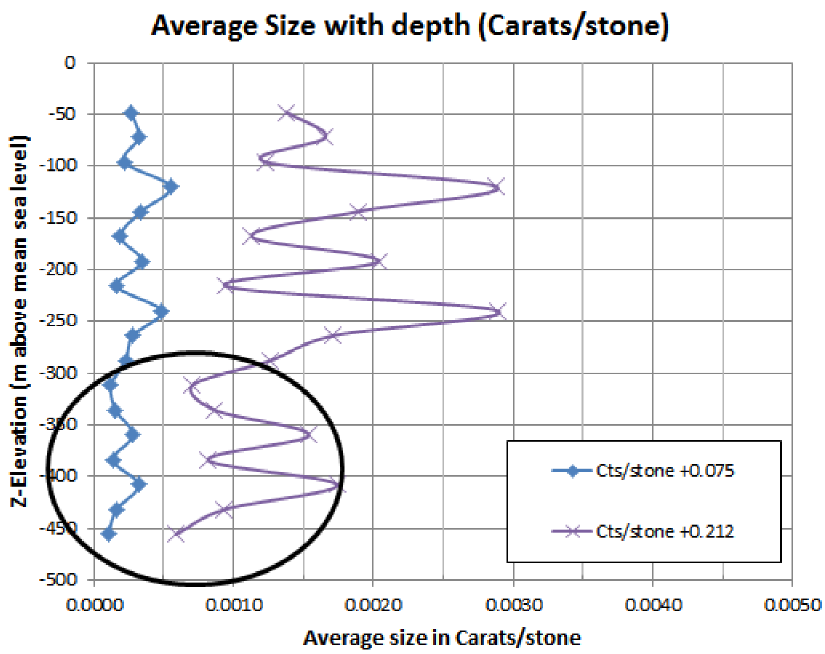


Figure 6-2 : Average stone size in 24m benches with depth

The graphs suggest a decrease in average diamond size below -300m elevation.

6.1.4.2 Uniformity of diamond concentration

Average diamond concentration was calculated per bench and the values plotted as shown in Figure 6-3.

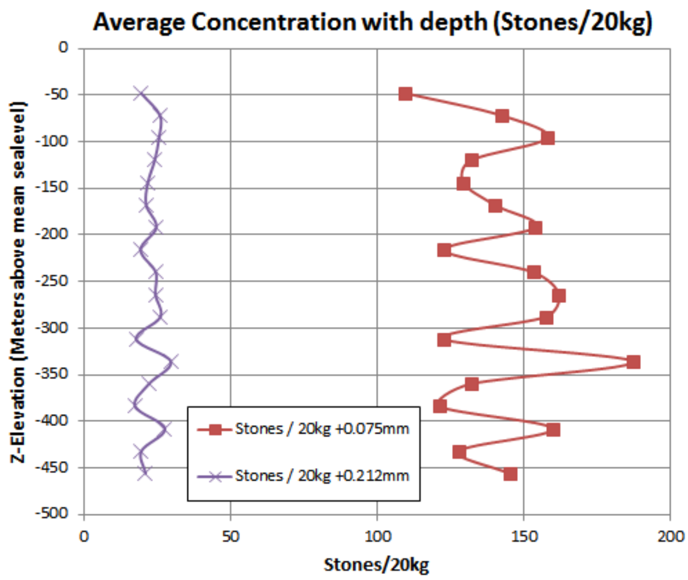


Figure 6-3 : Diamond concentration in 24m benches with depth

Average concentration is shown at +0.075mm and +0.212mm and the graphs indicate no trend with depth, but more variability below -300m elevation, introducing the need to split the domain into at least two depth zones.

Therefore, the approach adopted to examine the impact of the change in average size and concentration on diamond content was to assess diamond content as follows:

(i) For the total combined sample;
(ii) In 48m benches;
(iii) In two depth zones, above and below -272m elevation.

The options are discussed in the three following sections.

6.1.4.3 Diamond content based on combined sample

All the subsamples between -32 and -512m elevation were combined for the initial diamond content assessment. The diamond size distribution was modelled on the basis of microdiamond data and compared with macrodiamond data from the 100mm large diameter core sampling results. The size model parameters that were obtained were used to simulate a typical diamond parcel and the LP-graph of the typical parcel was compared with microdiamond sampling at +0.075mm as well as with macrodiamond results at +1.18mm. The comparison is shown in Figure 6-4.

The typical parcel replicates almost exactly the microdiamond samples as well as the macrodiamond sampling results, coming from an entirely different sampling program, suggesting that the model parameters are acceptable.

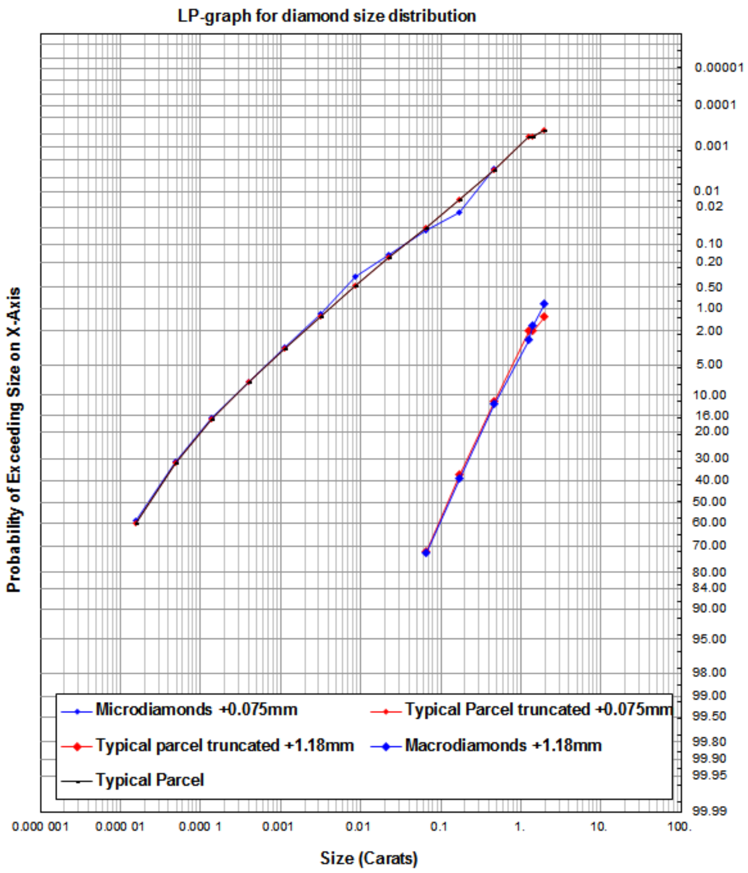


Figure 6-4 : Size distribution model based on combined microdiamond sample

Diamond concentration was modelled on the basis of the distribution of normalised stone counts for the 206 subsamples. Stone counts were normalised to a subsample weight of 16kg which is less than the minimum weight recorded for all the subsamples. In accordance with the work described in [15] normalisation was subsequently performed by drawing a 16kg diamond count for each subsample from a Binomial distribution $B(n, p)$, with

$$n = number\ of\ stones\ in\ the\ subsample$$

$$p = {}^{16}/_{(the\ subsample\ weight)}.$$

The histogram of adjusted stones/16kg was plotted and transformed into Gaussian values by means of Hermite polynomials.

Fifty thousand Gaussian values were simulated and back-transformed by means of the Hermite polynomial function, into values with the same distribution as seen for the adjusted 16kg sample stone counts.

The two histograms are shown on the left side in Figure 6-5.

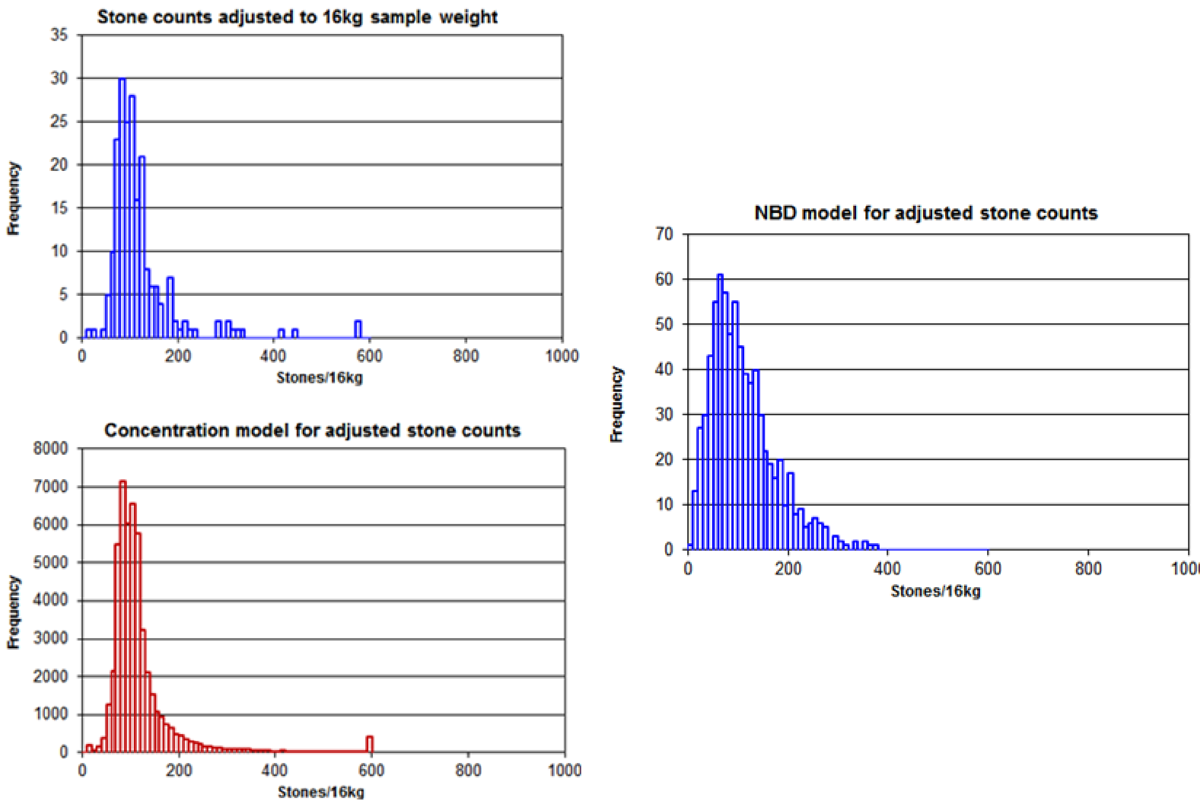


Figure 6-5 : Histograms of Diamond concentration in terms of stones/16kg, showing stone counts adjusted to subsample weight of 16kg. Below is a model based on Gaussian transform and on the side is a histogram based on the Negative Binomial Distribution.

As a matter of interest, the lognormal distribution is not appropriate in this case and with mean 122 and variance 4,664 the data rules out the Poisson distribution. The histogram for a Negative Binomial Distribution with this mean and variance is shown in

Figure 6-5 and seems inappropriate as well. The Gaussian transform function was used instead.

The 50,000 Gauss-transformed values were suitable to represent subsample stone counts for a typical parcel. Stone weights were allocated to the stones in each subsample in accordance with the modelled size distribution, forming a diamond parcel that would be typical of a parcel of diamonds from this source, both in terms of size and concentration.

LC-curves for typical parcel and corresponding micro and macrodiamond sampling data are shown in Figure 6-6.

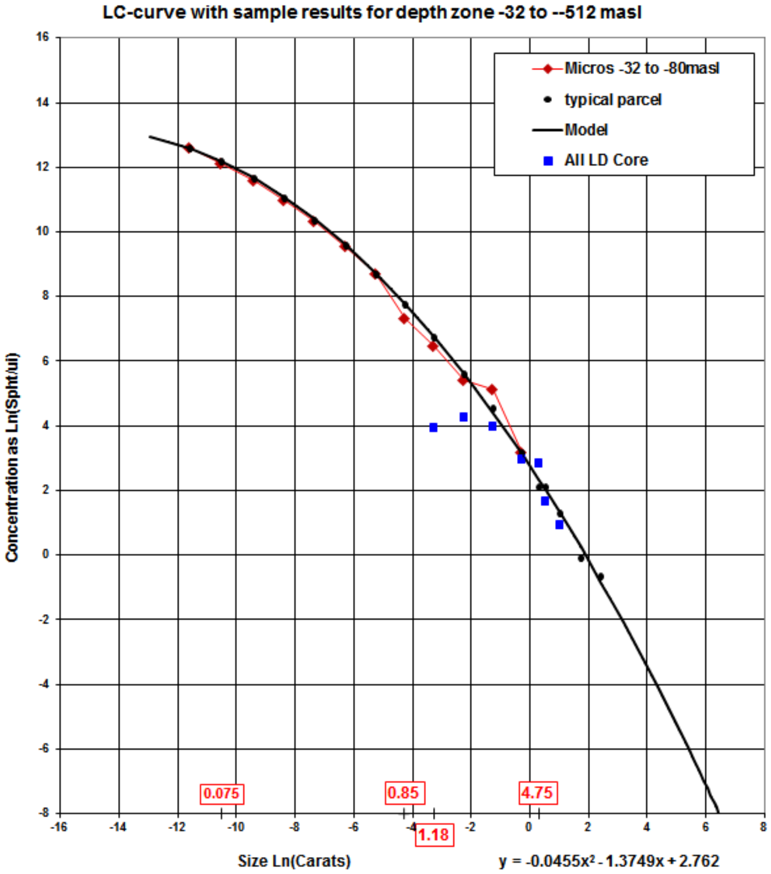


Figure 6-6 : LC-plots for sampling data and typical diamond parcel

The typical parcel was simulated to test the diamond content model by comparing diamond size and concentration obtained by simulation with the equivalent entities observed in micro and macrodiamond sampling. The red markers in the figure reflect microdiamond data, while the blue markers represent macrodiamond data from the LD core drilling program. The typical parcel and LC-model are indicated by the round black dots and the solid line.

The similarity between sampling and typical parcel is obvious and suggests that the models are acceptable.

Zonal diamond grade was estimated at 1.62 carats/ton (cpt), compared with sampling figures of 1.41cpt and 1.50cpt as shown in Table 6-2. The differences between modelled and sampled diamond grades are attributed to differences in material sampled and to screening and lockup losses during sampling.

The typical parcel reflects total diamond content without any losses and if normal recovery factors are applied to the bottom size classes, the grade reduces from 1.62cpt to 1.51cpt. Factors were estimated at 10% for recovery in size fraction +0.5 to -0.85mm and 50% in size fraction from +0.85mm to -1.18mm.

6.1.4.4 Diamond content by 48m bench

The 48m subdomains contained between 14 and 23 microdiamond subsamples with combined weight between 275kg and 542kg, which was sufficient for diamond size and concentration modelling.

Bench size distributions are shown in Figure 6-1.

LC-curves were derived per bench and used to estimate diamond grade. Results are shown in Table 6-4. The distinguishing factors between benches were diamond concentration and diamond size.

Table 6-4 : Results of microdiamond analysis for grade estimation per 48m bench

Subsample combination				Lognormal parameters		Parameters for LC-curve (second degree polynomial)			Estimated Carats/ton +0.85mm	Average Stones / 20kg
Bench top & Bottom	Bench mean elevation	No of sub-samples	Sample (kg)	Log Mean	Log Std dev	a	b	c		
-32 to -512	All	206	4155	-15.50	3.38	-0.0455	-1.3749	2.7620	1.62	156
-32 to -80	-56	14	275	-15.50	3.35	-0.0444	-1.3767	2.6378	1.46	156
-80 to -128	-104	27	543	-15.50	3.45	-0.0462	-1.3472	3.0080	1.98	142
-128 to -176	-152	18	358	-15.50	3.45	-0.0449	-1.3287	2.9708	1.87	129
-176 to -224	-200	21	418	-15.50	3.38	-0.0460	-1.3789	2.7259	1.58	149
-224 to -272	-248	23	469	-15.50	3.38	-0.0481	-1.4021	2.7242	1.63	154
-272 to -320	-296	23	458	-15.50	3.36	-0.0458	-1.3943	2.5706	1.40	150
-320 to -368	-344	22	449	-15.50	3.36	-0.0439	-1.3757	2.6707	1.52	165
-368 to -416	-392	21	427	-15.50	3.30	-0.0426	-1.3799	2.2403	1.00	129
-416 to -464	-440	23	469	-15.50	3.38	-0.0440	-1.3509	2.8076	1.66	149
-464 to -512	-484	14	289	-15.80	3.30	-0.0434	-1.4161	2.1657	0.99	161

Estimated average diamond grade per bench is shown in the table together with the parameters for diamond size and concentration. Results seem to confirm the idea of a split in the domain at -272m elevation.

From the values in the table it can be seen that estimated grade and average concentration do not correlate, as diamond size varies and has a significant effect on grade.

The LP-curves shown in Figure 6-1 indicate that the diamonds from the bottom bench -464m to -512m seems to have a finer size distribution compared with the rest of the benches in the kimberlite. This is also evident from Table 6-4 which shows the lowest log mean value for this bench. The lognormal parameters for the other benches are similar.

The low Grade estimate for the bottom bench was entirely due to the finer size distribution suggested by sampling. If indeed the size distribution is finer the impact on diamond value would be serious and was therefore not simply attributed to low stone numbers in the combined bench subsamples.

Estimates for diamond grade per bench were combined with bench tonnes to calculate zonal diamond grade. Table 6-5 shows a bench by bench breakdown of estimated diamond content in carats, based on the grade estimates derived from microdiamond sampling shown in Table 6-4.

Table 6-5 : Summary of in-situ diamond content.

48m bench base elevation	Volume x1000	Tonnages x1000	carats / tonne	Carats x1000
-80	1,110	2,653	1.46	3,873
-128	2,451	5,784	1.98	11,452
-176	1,899	4,558	1.87	8,523
-224	1,536	3,763	1.58	5,946
-272	1,233	3,107	1.63	5,064
-320	1,105	2,829	1.40	3,961
-368	989	2,552	1.52	3,879
-416	861	2,247	1.00	2,247
-464	783	2,051	1.66	3,405
-512	794	2,088	0.99	2,067
		31,632	1.59	50,418

Bench totals suggest a zonal diamond content amounting to 50million carats at an average grade of 1.59 carats/ton. The 48m bench approach provides a first step towards local diamond content.

For the final assessment the kimberlite was split into two domains above and below -272m elevation.

6.1.4.5 Zonal diamond content above and below -272m elevation

The bench by bench breakdown in the previous section indicates a possible change in diamond content characteristics at approximately -272m elevation. Average diamond size seems to decrease and diamond concentration seems to become more variable in subsamples below this elevation.

Sampling data was thus split into groups above and below -272m elevation, as shown in Table 6-6.

Table 6-6 : Microdiamond data above and below -272m elevation

Depth below sea level (m)	-32 to -272	-272 to -512
Number of Samples	103	103
Sample weight	2,063.4	2,091.4
+ 4.75 mm	0	0
+ 3.35 mm	1	0
+ 2.36 mm	5	2
+ 1.70 mm	7	2
+ 1.18 mm	19	10
+ 0.85 mm	29	32
+ 600 µm	137	127
+ 425 µm	318	281
+ 300 µm	669	672
+212 µm	1,260	1,298
+150 µm	2,342	2,413
+106 µm	4,092	4,377
+ 75 µm	6,230	6,547
TOTAL	15,109	15,761
Stones/20kg +0.106	86	88
Stones/20kg +0.150	46	46
Stones/20kg +0.212	24	23

A comparison of the distribution of diamond size for the two zones is shown in Figure 6-7.

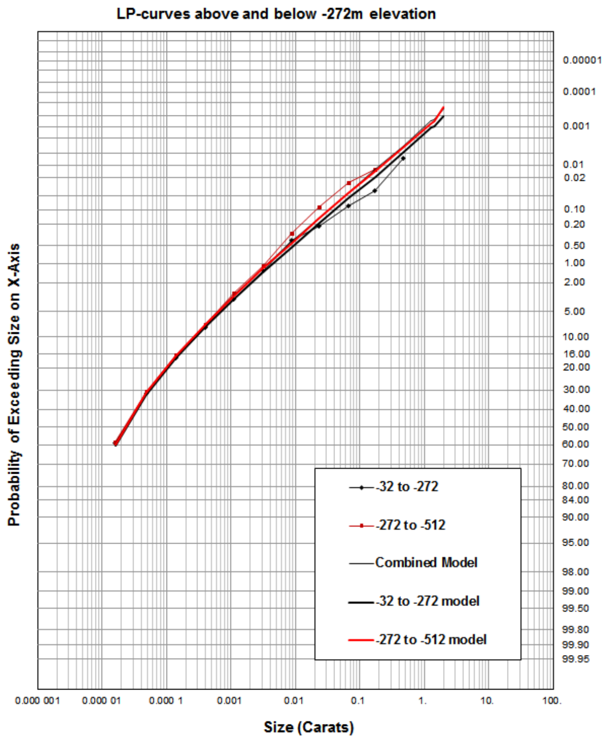


Figure 6-7 : Comparison of diamond size distribution above and below -272m elevation

The slight difference in diamond concentration was attributed to low stone frequencies in the size classes involved and was ignored. The stone count distribution for the total combined sample was used to represent diamond concentration, using the 50,000 values simulated for the combined zonal estimate in the previous section.

With the two diamond size distribution models diamond content was calculated for each depth zone via two simulated typical parcels, as before.

Table 6-7 : Results of diamond content analysis for samples above and below -272m elevation

Subsample combination				Lognormal parameters		LC-curve (polynomial)			Grade estimate +0.85mm cts/ton	Mean St/20kg +.075mm
Bench top & Bottom	Bench mean elev.	Sub sample #	Sample (kg)	Log Mean	Log Standard Deviation	a	b	c		
-32 to -272	-157	103	2063	-15.50	3.40	-0.0447	-1.3583	2.8535	1.75	146
-272 to -512	-392	103	2091	-15.50	3.35	-0.0479	-1.4217	2.5380	1.40	151

The difference in diamond grade above and below -272m elevation is entirely due to the difference in the distribution of diamond size in the two domains. If this difference is real it should be detected in the grades for macrodiamond samples from large diameter drilling.

6.1.4.6 Zonal estimates compared with LDD macrodiamond results

The more representative 100mm macrodiamond sampling results were grouped into the same 48m benches used for microdiamonds and compared with bench estimates obtained from microdiamonds. A summary of the LDD data is given in Table 6-8.

Table 6-8 : Summary of 100mm LDD sampling data by 48m bench.

Z-Elevation (masl)	No of Samples	Sample wt kg	Stones+ 0.5mm	Carats +0.5mm	Stns/ tonne +0.5	Cts / stone +0.5mm	Cts / tonne +.5mm	Stones / tonne +1mm	Cts / stone +1mm	Cts / tonne +1mm
-32 / -80	39	5,734	607	12.16	106	0.0200	2.12	33	0.0536	1.79
-80 / -128	104	17,656	1801	28.93	102	0.0161	1.64	26	0.0494	1.29
-128 / -176	93	15,830	1574	25.05	99	0.0159	1.58	27	0.0471	1.27
-176 / -224	73	10,038	1102	19.17	110	0.0174	1.91	27	0.0565	1.54
-224 / -272	43	7,414	904	13.53	122	0.0150	1.83	28	0.0512	1.44
-272 / -320	44	6,874	735	9.85	107	0.0134	1.43	23	0.0476	1.09
-320 / -368	29	4,800	551	6.33	115	0.0115	1.32	24	0.0399	0.94
-368 / -416	23	3,600	494	8.41	137	0.0170	2.34	34	0.0549	1.89
-416 / -464	20	2,991	333	4.51	111	0.0135	1.51	25	0.0448	1.14
-464 / -512	20	3,415	518	6.58	152	0.0127	1.93	37	0.0394	1.44
-32 / -272	352	56,673	5988	98.83	106	0.0165	1.74	28	0.0507	1.40
-272 / -512	136	21,680	2631	35.68	121	0.0136	1.65	27	0.0456	1.25
Total	488	78,352	8619	134.52	110	0.0156	1.72	28	0.0493	1.36

Diamond concentration and average stone size graphs are shown in Figure 6-8

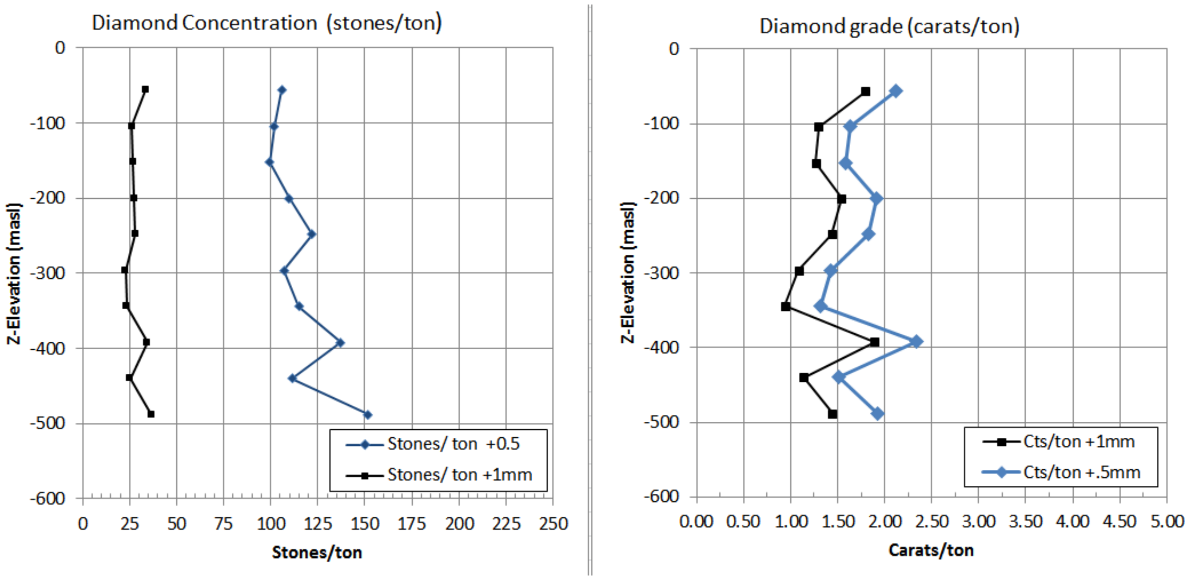


Figure 6-8 : Large diameter macrodiamond concentration and grade in 48m benches.

The graphs depict diamond concentration in stones/tonne and diamond grade in carats/tonne at bottom cut-off levels of +0.5mm and +1mm in accordance with the way the data was recorded.

The following is noted with regard to diamond grade and concentration displayed in Table 6-8 and Figure 6-8:

(i) Almost 4 times as many stones were recovered at +0.5mm compared with recovery at +1mm (110 and 28 stones/ton);

(ii) Average bench concentration at +0.5mm recovery is more variable than at +1mm;

(iii) +1mm stone concentration seems to remain constant with depth, with a slight increase in variability below -350m elevation. This is most likely due to a reduction in the number of samples available with depth.

(iv) +0.5mm stone concentration seems to increase with depth below -150m elevation. This could be in line with the suggestion of a decrease in average diamond size with depth by microdiamond sampling;

(v) The variability in diamond grade (carats/tonne) is due mostly to the variability in diamond size.

Figure 6-9 depicts average macrodiamond size with depth.

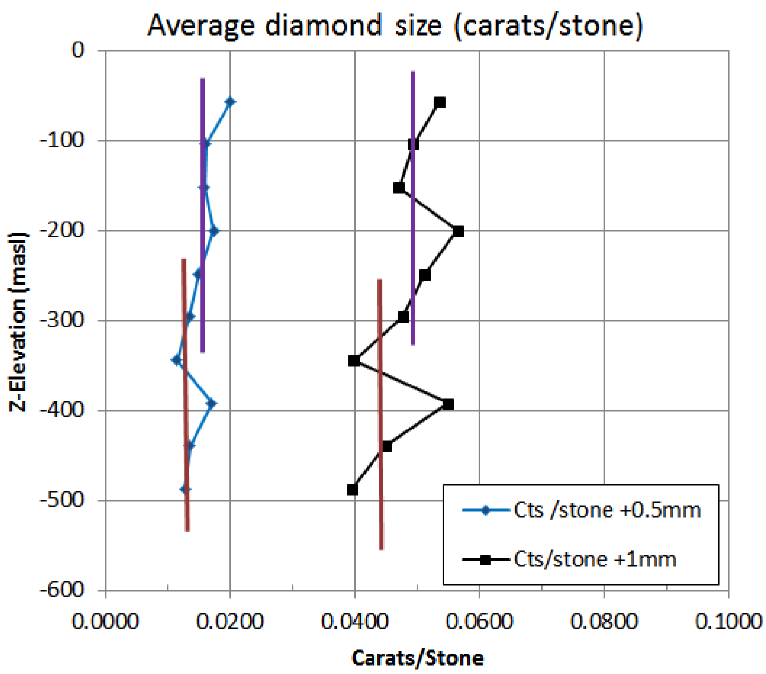


Figure 6-9 : Large diameter macrodiamond average stone size in 48m benches

The change in average size at approximately -300m elevation seen in microdiamond sampling is thus confirmed by the behaviour of the macrodiamond sample.

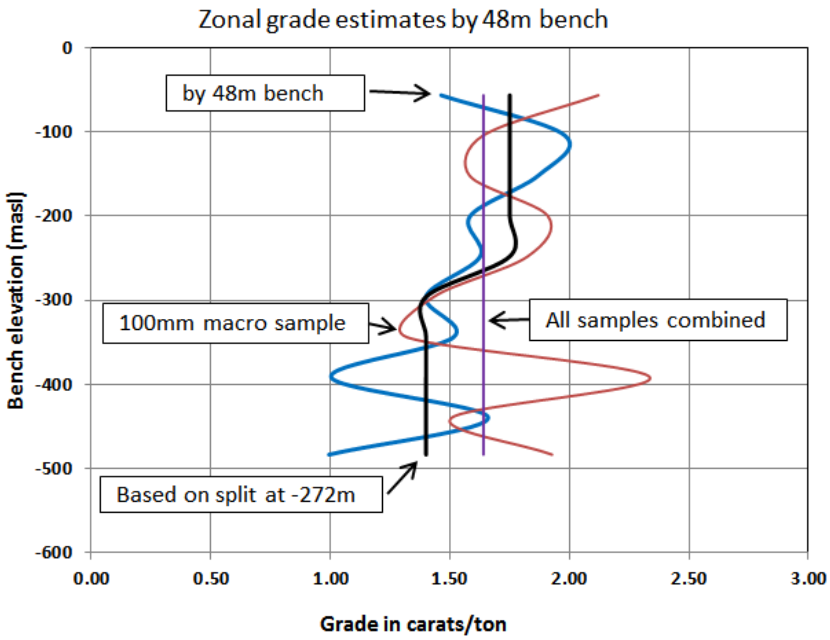
The LP-plots per 48m bench suggest less variability in diamond size compared with the calculated bench averages. Table 6-9 summarises the three estimates at +0.85mm with the corresponding sample macrodiamond grade at +0.5mm.

Table 6-9 : Zonal diamond grade comparison of results from sections 6.1.4.3, 6.1.4.4 and 6.1.4.5

Bench top & Bottom elevation	Bench Tons x 1000	Estimate by 48m bench		Estimate based on samples split at -272m		Estimate based on all samples -32m to -516m		100mm macro sample	
		Grade carats/ton	Carats +0.85mm	Grade carats/ton	Carats +0.85mm	Grade carats/ton	Carats +0.85mm	Grade carats/ton	Carats +0.5mm
-32 to -80	3,525	1.46	5,157	1.75	6,169	1.64	5,781	2.12	7,474
to -128	7,703	1.98	15,260	1.75	13,480	1.64	12,633	1.64	12,620
to -176	6,052	1.87	11,305	1.75	10,591	1.64	9,925	1.58	9,576
to -224	4,997	1.58	7,917	1.75	8,745	1.64	8,195	1.91	9,543
to -272	4,137	1.63	6,728	1.75	7,240	1.64	6,785	1.83	7,551
to -320	3,762	1.40	5,263	1.40	5,267	1.64	6,170	1.43	5,391
to -368	3,395	1.52	5,143	1.40	4,753	1.64	5,568	1.32	4,479
to -416	2,987	1.00	2,997	1.40	4,182	1.64	4,899	2.34	6,979
to -464	2,727	1.66	4,525	1.40	3,818	1.64	4,472	1.51	4,110
to -512	2,779	0.99	2,762	1.40	3,891	1.64	4,558	1.93	5,355
	42,064	1.59	67,057	1.62	68,135	1.64	68,985	1.74	73,079

Estimated diamond content at +0.85mm for the three different approaches are similar, but is slightly lower compared with sample grades due to the lower sample bottom cut-off at +0.5mm.

Figure 6-10 shows a graphic comparison of estimated grade in the 48m benches.



The 48m bench estimates take account of variation in size and concentration as suggested by microdiamond sampling.

The estimate based on a split at -272m elevation takes care mostly of the apparent change in diamond size distribution at this elevation (Stone concentrations in the two domains are similar at 146 and 151 stones/20kg).

Figure 6-10 : Comparison of grade estimates.

The single estimate based on all microdiamond samples between -32m and -512m provides an estimate for zonal diamond content as reflected by the combined microdiamond sample and ignores the variation in size and concentration seen in the breakdown with depth.

Macrodiamonds from the 100mm LD sampling indicate high variability in bench average diamond grade, but this is mainly due to the variability in average diamond size and is exacerbated by sparse information below -300m elevation. It is difficult to believe that diamond grade does actually vary this much with depth on this basis.

The existence of a single diamond size distribution seems unlikely and the choice will eventually probably lie between a split at -272m elevation or using 48m bench breakdown.

All three scenarios will have to be used in economic studies. The sensitivity of mining economics to the scenarios will determine whether more sampling would be required in risk assessment studies.

The three scenarios delivered almost identical average zonal grade and diamond content.

6.1.5 Average recoverable diamond grade and value

The diamond size distribution model was combined with the distribution of diamond value to derive average diamond value associated with a realistic production diamond parcel. Average diamond value per size class observed in the valuation parcel was used to model expected value per size class.

Losses due to screening and diamond lockup will eventually have an effect on recoveries in the smaller size classes, which will have to be factorised to yield a recoverable size distribution.

This size distribution was used to estimate average recoverable diamond grade and value. A consequence of the high intensity of small stones was that diamond grade and value would be highly sensitive to the truncation level selected and the recovery factors applied.

6.1.5.1 Diamond value per size class

Macrodiamonds recovered from the domain were valued by sieve class and the average values are shown in Table 6-10.

Table 6-10 : Diamond value by sieve size class.

Size class	Lower CS	Av size carats	Carats	Stones	Dollar value	Dollar/carat	
						Actual	Estimate
20+	19.8	23.95	71.85	3	34,534	480.6	160
15+	14.8	18.29	36.58	2	6,000	164.0	160
+23	8.036	11.46	22.92	2	3,456	150.8	160
+21	3.691	4.82	141.51	30	34,567	244.3	160
+19	1.918	2.74	102.23	38	9,000	88.0	140
+17	1.423	1.65	56.26	34	2,831	50.3	120
+15	1.195	1.29	40.96	32	4,328	105.7	110
+13	0.703	0.91	121.18	131	11,122	91.8	90
+12	0.523	0.61	60.59	99	4,795	79.1	75
+11	0.317	0.41	71.44	169	4,408	61.7	62
+ 9	0.179	0.23	50.86	217	2,512	49.4	47
+ 7	0.117	0.14	19.30	136	605	31.3	36
+ 6	0.079	0.094	10.44	110	322	30.9	30
+ 5	0.049	0.060	6.31	107	148	23.4	24
+ 3	0.026	0.035	2.06	58	54	26.0	18
+ 2	0.019	0.020	0.54	27	8	14.6	14
+ 1	0.011	0.013	0.00	0	0		11
-1	0.005	0.010	0.04	4	0		10
			815.07	1,199	118,690	145.62	

The table shows the number of stones per size class, total Dollar value and the average diamond value in Dollar per carat (Dpct). Prices are quoted in US Dollar and size classes are in accordance with the DTC size classification system.

Average diamond value by size class was plotted against diamond size to develop a model for the change of diamond value with diamond size. Diamond value is represented by the logarithm of class average, while diamond size is represented by the logarithm of class average size. The relationship is shown in Figure 6-11.

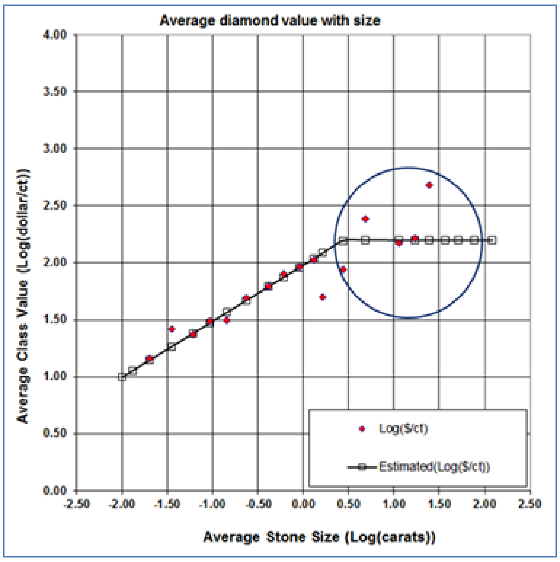


Figure 6-11: Class value with size.

None of the top three size classes contains more than 3 stones and the next four size classes contain between 30 and 40 stones per class, resulting in high variability of average value as shown.

Values below the trend line suggested by the rest of the size classes were ignored for modelling purposes. Instead, the suggested trend line was extrapolated upwards and a maximum average value of 160 $/ct was assumed for all larger stones.

Extrapolation was based on what is seen at most other diamond producers where the full diamond assortment is known. This assumption must be highlighted in reporting for confirmation when more macrodiamonds become available for valuation.

Class average and modelled values are shown in Table 6-10.

Average diamond value for the resource derived from this relationship will have to be revised when more data becomes available, but should give a good indication of the value to be expected when mining the resource.

6.1.5.2 Diamond content in commercial sieves

The LC-curve shown in Figure 6-6 was used to derive diamond grade broken down into commercial diamond sieve classes.

The breakdown is shown in Table 6-11, including diamond value per sieve class as shown in Table 6-10.

Table 6-11 : Breakdown of diamond grade and value into diamond sieve categories

Alignment factor	Sieve Class	Grade cts/ton	%carats	Diamond Value ($/ct)	Class Dollars per 100cts	Cumulative % Value
1	450+	0.003	0.148	160	24	0.49
1	400+	0.001	0.032	160	5	0.60
1	350+	0.001	0.040	160	6	0.73
1	300+	0.001	0.052	160	8	0.90
1	250+	0.001	0.070	160	11	1.14
1	200+	0.002	0.101	160	16	1.47
1	150+	0.003	0.157	160	25	1.99
1	100+	0.005	0.286	160	46	2.94
1	60+	0.009	0.497	160	80	4.60
1	45+	0.007	0.365	160	58	5.81
1	30+	0.012	0.643	160	103	7.95
1	20+	0.016	0.824	160	132	10.69
1	15+	0.014	0.716	160	115	13.07
1	+23	0.036	1.916	160	307	19.44
1	+21	0.065	3.433	160	549	30.84
1	+19	0.075	3.940	140	552	42.30
1	+17	0.041	2.159	120	259	47.68
1	+15	0.026	1.374	110	151	50.82
1	+13	0.089	4.691	90	422	59.59
1	+12	0.056	2.961	75	222	64.20
1	+11	0.106	5.576	62	346	71.38
1	+ 9	0.137	7.197	47	338	78.41
1	+ 7	0.112	5.878	36	212	82.81
1	+ 6	0.109	5.734	30	172	86.38
1	+ 5	0.144	7.583	24	182	90.16
1	+3	0.196	10.305	18	185	94.01
1	+1.18mm	0.035	1.865	16	30	94.63
1	+2	0.064	3.365	14	47	95.61
1	+1	0.175	9.232	11	102	97.72
1	0.85mm	0.059	3.087	10	31	98.36
1	0.6mm	0.300	15.772	5	79	100.00
	Total	1.901	100.000		4,814	

The table shows diamond grades in carats per ton at +0.6mm. The distribution of diamond content is expressed as a percentage, which is used to calculate total Dollar per 100 carats, from which the average resource Dollar per carat is derived.

The last column in the table shows percentage of value lying above each size class. The first column shows the class alignment factor, which is unity when presenting in situ diamond grade. The table was used to calculate the effect of truncation on diamond grade and value.

Truncation was applied at each size class up to +9 diamond sieve and the resulting grade and value calculated as shown in Table 6-12 and depicted in Figure 6-12.

Table 6-12 : Truncation effect on diamond grade and value

Class lower limit (cts)	Truncation Sieve	Average value $/ct above truncation	Average Grade (cpht) above truncation	Average value ($/ton) above truncation
0.1790	+ 9	102	71	72
0.1170	+ 7	93	82	76
0.0792	+ 6	85	93	79
0.0485	+ 5	77	107	83
0.0256	+3	68	127	86
0.0228	+1.18mm	66	130	86
0.0186	+2	64	137	87
0.0106	+1	58	154	89
0.0087	0.85mm	56	160	90
0.0031	0.6mm	48	190	91

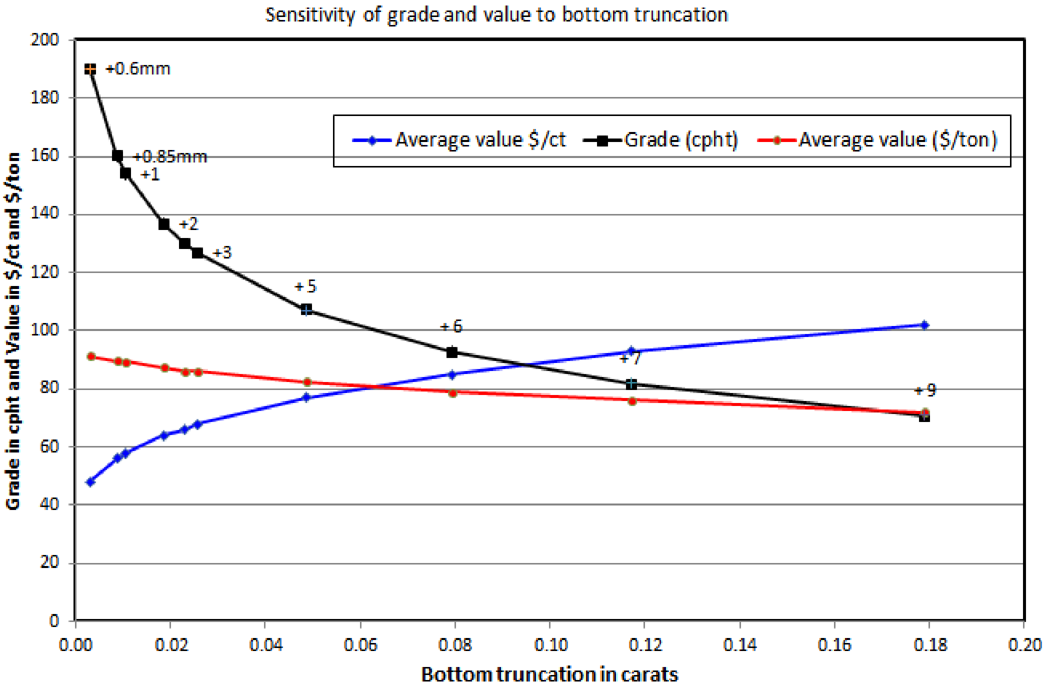


Figure 6-12 : Truncation effect on grade and value.

Sensitivity of grade and value in Dollar/ct on changes to bottom truncation is clearly illustrated, with revenue in terms of Dollar/ton shown to be less severely affected.

If recovery of -1.18mm material is more costly than the value of -1.18mm diamonds, justification for their recovery will be difficult.

High quality of small stones will be evident in the value curve and will ultimately reflect on diamond revenue ($/ton), which will show a sharper decline when bottom truncation level is increased.

6.1.5.3 Alignment factors with recoverable grade and value

The sensitivity curves shown in Figure 6-12 underline the importance of selecting an optimal bottom truncation level in the recovery process.

Equally important is the determination of adjustment factors associated with a truncation level in order to present the mine planners with an appropriate grade and diamond value for planning purposes.

A set of suggested alignment factors associated with recovery at +1.18mm is shown in Table 6-13.

A 30% reduction in grade is demonstrated, reducing grade from 1.9 to 1.33 carats/ton, but this is accompanied by an increase in Dollar per carat from 48 to 65 due to the loss of a large portion of low value small stones.

Table 6-13 : Application of alignment factors.

Alignment factor	Sieve Class	Grade (cpht)	% Reduction in grade
1	+ 6	0.109	0.000
1	+ 5	0.144	0.000
0.9	+3	0.176	1.031
0.6	+1.18mm	0.021	0.746
0.4	+2	0.026	2.019
0.2	+1	0.035	7.386
0.01	0.85mm	0.001	3.056
0	0.6mm	0.000	15.772
		1.330	30.009

The illustration also shows why it is not feasible to simply apply an overall 'recovery factor' to diamond grade, but leave average diamond value unchanged.

Of the three scenarios considered in the previous sections only the one based on all sampling information between -32m and -511m elevations was used to show the impact of bottom truncation on grade and revenue.

The same scenario was used to assess the value of the recoverable resource between these elevations in terms of USD and is summarised in Table 6-14.

Table 6-14 : Zonal domain estimated recoverable diamond content.

Bench top & Bottom elevation	Bench Tonnes x 1000	Grade carats / tonne	Diamond content in Carats x1000	Average Value USD/ct	Class USD (millions)
-32 to -80	2,653	1.33	3,528	65	229
-80 to -128	5,784	1.33	7,693	65	500
-128 to -176	4558	1.33	6,062	65	394
-176 to -224	3763	1.33	5,005	65	325
-224 to -272	3107	1.33	4,132	65	269
-272 to -320	2829	1.33	3,763	65	245
-320 to -368	2552	1.33	3,394	65	221
-368 to -416	2247	1.33	2,989	65	194
-416 to -464	2051	1.33	2,728	65	177
-464 to -512	2088	1.33	2,777	65	181
	31,632	1.33	42,071		2,735

Recoverable diamond content between elevations -32m and -512m comprises 42m carats in 31.6m tonnes at an average grade of 1.33 carats/tonne (+1.18mm) and an average value of 65 USD. The total value of the domain considered in this mineral resource is estimated at approximately 2.7 billion USD.

A resource block model that distributes this resource into mining blocks appropriate for mine planning purposes was not considered for inclusion in the thesis.

6.1.6 Local diamond content estimation

Analysis thus far suggests that the use of sample diamond grade (carats/ton) for resource estimation could lead to unrealistic local estimates due to the effects of single large stones.

Sample stone concentration (stones/ton) should therefore be used to determine local estimates for diamond potential. Diamond content is derived from diamond potential and a diamond size distribution modelled for the domain considered.

Apart from being more variable below -300m elevation, average sample stone count does not show any trend with depth. Sample values can thus be used in a spatial statistical analysis to determine local estimates for diamond potential.

Local diamond content is derived from estimated (local) diamond potential and the diamond size distribution for the active domain, in accordance with the Cox process. A detailed spatial block model may be developed in this phase, based on local estimates derived from close spaced core drilling. The variable used for local estimation is sample stone density.

Conventional spatial statistical modelling can be carried out with all the related spatial models. However, the Cox simulation based on mixed sample support could be applied to make use of multiple sets of samples based on different sample support size. [3].

Local estimation based on microdiamond sampling forms part of separate research that is being carried out.

6.2 Reliability

The resource is stated in benches and is sufficient for this resource as selective mining is not anticipated from the domain.

Pipe geometry is important to outline the domain. Horizontal variability will have lesser effect on mining, but changes in grade with depth may be important. It is suggested that microdiamond sampling provides a more reliable reflection of possible changes with depth.

For all practical purposes the large diameter core drilling results have not justified its presence. The diamonds contributed to value, but their contribution towards diamond size distribution modelling was non-existent, as this was done perfectly well with the diamonds from large diameter RCD.

Data required for the status of the resource as it stands was effectively obtained from microdiamond and RCD sampling.

Instead of large diameter core drilling more NQ-core could have been drilled to improve pipe geology and geometry as well as provide more material for microdiamond sampling. With more microdiamond data per bench the bench estimates could be improved. It might be possible to subdivide benches into horizontal domains for a breakdown of the resource into even smaller subdomains. Such an option would have been more cost effective and could provide a more superior resource model stated in sufficient detail to eliminate the need for local estimation.

If the scenario of a common diamond size distribution for the entire domain is accepted it is possible to provide confidence limits for grade on the basis of the distribution of diamond concentration in accordance with the simulation graphs shown in Figure 3-14. With slightly more than 200 subsamples in this sampling database the domain diamond concentration derived from the combined sample will be within 3% of the combined sample mean. Domain diamond grade is modelled on the basis of the combined sample mean concentration and upper and lower limits for the grade estimate will consequently be 3% above and below the calculated grade estimate.

6.3 Conclusion

Detailed sampling such as for this study is also applicable when an existing resource needs to be extended with depth.

It is possible to carry out detailed sampling based on microdiamond sampling over a number of years at an operating mine. The use of core drilling allows angled holes which can be drilled from outside the actively mined areas without affecting production and mining operations.

Detailed mine extension programs are being carried out at major kimberlites in Southern Africa. These programs have all been initiated on the basis of this research.

7 Conclusion and Perspective

Microdiamonds in the diamond size assortment has been recognised since the early 1900's and has been used initially to provide an indication of the presence of diamonds and later to give an indication of diamond grade. However, it has never been 'embraced' as sampling tool other than possibly at Argyle mine in Australia.

The thesis summarises work that has been in progress since 2003 when De Beers created a research team to examine ways of reducing the time between the discovery and mining of diamond deposits. The most important aspect culminating from this research is proof of general application potential of this methodology and the establishment of a practical and simple sampling and estimation methodology to assess kimberlite diamond content based on the results of microdiamond sampling.

The Log-Probability curves shown in the figure are for microdiamond sampling and production data at an operating mine, illustrating the result in practice.

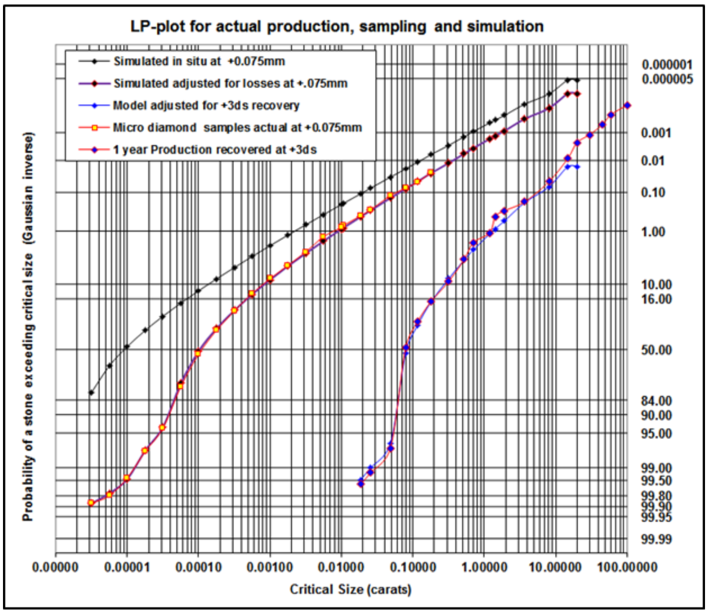


Figure 7-1 : Current mine LP-curve for production and sampling

A combined microdiamond sample is shown with production data recorded for one year, demonstrating complete coherence between the two sets of data with respect to the distribution of diamond size. The actual diamond size assortment is fully reproduced by means of a simulation model based on a 2-parameter lognormal size distribution.

It is irrelevant whether microdiamonds come from a different diamond population, or whether they are formed by a different process, compared with macrodiamonds. There is empirical evidence of the existence of a continuous size distribution of diamonds in kimberlite, and the validity of the lognormal distribution as statistical distribution of diamond size in kimberlite is observed consistently, supporting it as basis for diamond content modelling.

The methodology developed to estimate in situ diamond content in kimberlite is simple, easily executable and if carried out properly, errors are quickly and clearly exposed by the visual nature of the process. It takes account of bottom cut-off recovery effects and is capable of handling sampling results from multiple programs involving different treatment and recovery processes.

Methodology can only reflect what sampling results have produced. The question will always remain whether and how well a kimberlite is being represented by sampling. The text provides motivation for application of correct sampling procedures. An important sampling aspect is that a kimberlite with lower diamond concentration requires a larger eventual sample for reliable estimation. Larger subsamples improve the chance of representing the size distribution and more subsamples improve the chances of representing the distribution of diamond concentration.

Diamond content estimation is entirely dependent on reliable geological information. Core drilling is the ideal source of geological information and is also suitable for microdiamond sampling. Therefore, a sampling protocol specifying proper geological controls combined with efficient microdiamond recovery procedures will provide valuable diamond content information from the onset of sampling. Non-viable deposits are quickly identified and potentially viable deposits are sampled in phases progressively towards feasibility or are abandoned without a long drawn out sampling campaign.

The underlying requirement of being restricted to a stationary domain underlines the importance of deposit geology. The illustration demonstrates the importance of geological controls and the uniqueness of litho-facies also in terms of the diamonds contained.

Table 7-1 : Illustration of extreme discontinuity between domains.

hole/sample		from	to	geology	kg	stones	carats	st/20kg
1	101	2.8	4.5	VK	8.1	54	0.050	134
1	102	6.8	8.5	VK	12.7	92	0.040	144
1	103	8.7	10.4	VK	12.3	88	0.014	143
1	104	12.6	14.4	VK	13.7	108	0.061	158
1	105	14.7	16.5	VK	16.2	125	0.051	154
1	106	18.8	20.5	VK	12.0	67	0.104	112
1	107	20.7	22.5	VK	11.9	65	0.014	109
1	108	24.7	26.5	VK	14.1	103	0.126	146
1	109	26.8	28.6	VK	13.3	76	0.024	114
1	110	30.8	32.6	VKBR	12.4	15	0.019	24
1	111	32.9	34.7	VKBR	13.0	22	0.013	34
1	112	36.9	38.7	VKBR	13.6	8	0.011	12
1	113	39.0	40.8	VKBR	13.8	32	0.052	46
1	114	43.0	44.7	VKBR	12.2	24	0.131	39
1	115	44.9	46.6	VKBR	12.9	8	0.020	12
1	116	48.8	50.6	VKBR	14.0	10	0.007	14
1	117	50.8	52.6	VKBR	13.3	35	0.032	52
1	118	54.8	56.6	VKBR	12.8	5	0.012	8
1	119	56.8	58.6	VKBR	13.1	9	0.016	14
1	120	60.8	62.6	VKBR	13.5	10	0.003	15

The last column in Table 7-1 contains subsample microdiamond concentration in terms of stones per 20kg sample weight. The hole intersects a second litho-facies which clearly has lower diamond concentration and as a consequence most likely also lower diamond content. Sub samples from these domains should not be combined. Therefore microdiamond concentration may in some cases be used to distinguish between different kimberlite domains.

As integral part of the total diamond assortment it is obvious that microdiamond concentration is a regionalised variable. It can therefore be used in spatial analysis for local diamond content estimation and to create a resource block model for mine feasibility studies.

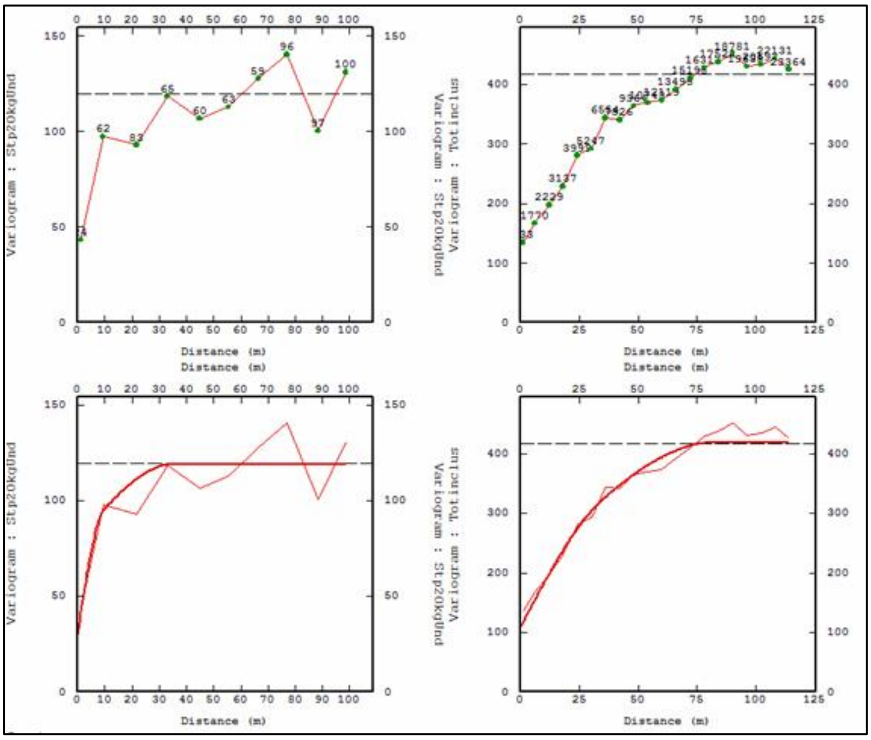


Figure 7-2 : Microdiamond concentration is regionalised.

The example of spatial structure for stone concentration on the left and kimberlite dilution shown on the right in the figure only materialises this way if enough subsamples are available and if subsamples contain enough stones. Dilution of kimberlite with non-kimberlite inclusions has high impact on diamond content. It could be analysed as co-variable with concentration and for some deposits may actually turn out being more important than the microdiamonds.

This is an indication that microdiamond sampling is suitable for zonal diamond content estimation from the early sampling phases as well as during advanced sampling for pre-feasibility and feasibility studies.

Progress required

Research should be done on the current accuracy and efficiency of local grades based on macrodiamonds. Current macrodiamond estimation methods might not always be justified on the basis of the quality of the data that is often available. It is possible that more may be expected from microdiamond sampling than what can actually be delivered by macrodiamond sampling and when results are not satisfactory, that macrodiamond sampling will still be preferred.

Research is being conducted on the analysis of diamonds within kimberlite by means of X-Ray tomography. Procedures are being researched in South Africa and will provide an interesting contribution to the Industry. The influence on estimation methodology needs investigation.

Sample reduction methods to explore the middle part of the size population must be considered, especially in cases where the size distribution is coarse and diamond concentration is low. Examining the application in the case of coarse caustic fusion technology for low concentration, coarse size distribution deposits, will be an interesting project, which may even contribute towards diamond value estimation based on microdiamond sampling.

Some issues pointed out in the thesis are being addressed currently, such as a more elegant way of providing confidence intervals for the diamond size distribution model. Research is being conducted with respect to alternative statistical models to represent the distribution of diamond size.

Methods of transition from microdiamond concentration to commercial size grades are required for local estimation. At Argyle Mine in Australia microdiamond concentration is high and subsamples yield high stone counts. Under those conditions the stone concentrations in selected size classes are correlated with commercial grade and assigned to individual subsamples, which are subjected to spatial analysis in the usual sense. This is feasible only if diamond concentration is high.

Local estimation is not addressed in the text but the research shows that when sufficient stones are present in a sample then it is possible to assign a commercial grade to the sample. The associated procedures must be investigated. The need for local estimation is associated with the character of the deposit. For instance, Russian diamond mines in particular operate on the basis of specifying their resource in terms of super blocks, which is a situation that is ideal for application of microdiamond sampling and estimation methodology. If stone concentration is not high then estimation can be carried out in 'super blocks', on the basis of limited drilling. If more detail is required these blocks may be reduced in size as more subsamples are added to the sampling data base.

The effect of allocating instead of sieving microdiamonds into size classes needs to be examined. Diamonds from macrodiamond sampling are sieved into size classes, which is inconsistent with microdiamonds that are allocated to size classes on the basis of their weights. It is suspected that the adverse effects of allocating (and not sieving) +0.3mm stones from microdiamond sampling may be significant.

The methodology is not without risk. With correct sampling and estimation procedures and proper risk assessment measures in place, it is possible to minimise uncertainty and provide assurances with respect to diamond content estimates based on microdiamond sampling.

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