Size distribution analyses for estimating diamond grade and value

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Abstract

Analysing the size frequency distributions (SFDs) of both micro diamonds and macro diamonds from primary deposits shows that the distributions are continuous across all sizes and that there are two regions of different character with a transition about 1–2 mm. Using log axes, the frequency curve is linear for the smaller sizes allowing slope and intercept parameters to be determined which are less ambiguous than stone counts and ratios of macro to micro populations that are generally reported. Modelling a diamond population that has undergone removal of a uniform thickness of the outer layer transforms a linear frequency curve into a quadratic form, which is also the form of the frequency curve for macro diamonds. Diamonds grown synthetically also display a linear distribution across a smaller fraction of their size distribution curve.

1. Introduction

Grade assessment is a key component of any new diamond resource evaluation. Depending on the degree of deposit development, these assessments can be based on either micro diamonds from drill samples or macro diamonds from bulk samples. Clearly the bulk samples provide more useful data, as not only are the diamonds more representative of a production scenario, but also they enable a quality assessment for price estimates. The analysis of micro diamond data is usually the basis upon which decisions are made to proceed to bulk sampling. A full understanding of the relationship between micro and macro diamond populations, coupled with the geology of the diamond source and an appreciation for the errors involved in any analysis, will ensure that potentially economic deposits are not overlooked and that unnecessary expenditure is not directed at uneconomic deposits.

Factors that are relevant to these deposit assessments include: the relationship between micro and macro distributions, sample size, classification technique (sieving regime, weights), and method of frequency calculation. Some of these aspects are addressed in this paper and apply to primary deposits with potential relevance to alluvial deposits.

With the recovery of significant quantities of macro diamonds from bulk sampling, there is an opportunity to both assign a value to the diamonds and to better describe the size population, enabling predictions of occurrences for large diamonds and

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plant recovery performance. Commonly the $/ct average price is determined by merely calculating the quotient of the diamond value and the carats recovered; however, this approach ignores any statistical appreciation of size populations and values.

In this paper, unless specified otherwise, the terms ‘macro’ and ‘micro’ are loosely used to refer, respectively, to those sizes recovered with pilot or production plants and those recovered in a laboratory. Where micro/macro ratios are discussed, the size transition is taken as 0.5 mm. As much of the data is considered commercially sensitive, the identity of the sources of data for the figures unfortunately cannot be disclosed.

2. Size frequency distribution

Frequency is determined by the quantity, \( N \), of diamonds within a carat size range, \( R \):

\[
\text{Frequency} = \frac{N}{R}
\]

where grade is of interest, the quantity of diamonds can be expressed in per tonne terms by dividing the frequency by the weight of the host rock sample.

It is common practice to size diamonds using screens rather than weights. In this instance, it is necessary to apply upper and lower nominal carat weights to each size fraction. These nominal weights can be assigned using an intuitive expression which assumes a shape profile that applies to all sizes. This expression is:

\[
\text{Nominal diamond weight} = k \times (\text{aperture size})^3
\]

where \( k \) is a constant determined so as to yield an appropriate mean stone size (MSS) for an upper and lower screen size. It is found that MSS \( \approx 0.9 \times \text{mean of upper and lower weights} \), the 0.9 factor arising from the higher population of lower weights.

Because of the wide range of sizes involved in a typical analysis, ranging over a few orders of magnitude, it is useful to present frequency figures logarithmically. The frequency can be plotted against the MSS for each size fraction, which is also best presented logarithmically. While it is common to plot size frequency distributions (SFDs) as a cumulative curve (Rombouts, 1997), it is submitted that such curves do not allow ready interpretation of frequency distributions and identification of anomalies.

3. Micro–macro relationship

There has been much discussion in the diamond industry about whether the micro and macro populations of diamond deposits are different. The only paper dealing specifically with the relationships between micro diamonds and macro diamonds is for the Argyle lamproite (Deakin and Boxer, 1989). Examination of numerous deposits across Australia, Canada and Africa reveals that the general profile of micro and macro SFDs is as shown in Fig. 1.

There are three notable features in this relationship:

- The micro frequency distribution is linear.
- The macro frequency distribution conforms to a second order polynomial (quadratic).
- Recovery losses are present in the smaller fractions of both the micro and macro populations.

![Fig. 1. Typical frequency curves for small and large size fractions of diamonds from the same deposit, showing a linear region across micro-diamond sizes and a curved region for macro sizes with a transition between the regions at 0.01 to 0.1 carats. A discrepancy is normally observed in the 0.1–0.01 ct range (log(mean stone size) of \(-2\) to \(-1\)) due to recovery inefficiencies for the commercial sizes. No severe discontinuities are observed between the micro and macro regions implying that the populations of the two fractions are related.](image-url)
As there is no severe discontinuity across the size ranges, it would appear that the populations are interrelated. It is accepted that there may be some deposits that have not been analysed by the authors in which different populations are evident. Support for a single dominant population within deposits is also provided by the size distributions recorded for diamonds grown synthetically using high pressure. Fig. 2 illustrates a plot for a distribution from a synthetic diamond production; the plot shows a similar frequency profile to that of natural diamonds.

It should be noted in Fig. 1 that the frequency discrepancy between the overlapping regions of the two curves is due to recovery methods involved. Diamonds recovered by acid digestion will be more efficiently extracted than the same size diamonds recovered by a production plant. The discrepancy can be significant, and in one instance an order of magnitude difference near the 0.05-ct size was recorded!

Where both micro and macro diamond data are obtained from a deposit, it is difficult to know the extent to which the micro diamonds recovered are representative of the much larger volume of host rock from which larger diamonds are recovered. In some instances there is a small frequency displacement between the two size ranges preventing them from being combined into a smooth distribution curve. Under these circumstances, it is assumed the micro diamonds are from a region having a grade different to that of the bulk sample host rock.

It is interesting to speculate why the size frequency distribution has two regions, and why the linear relationship does not extend to the large sizes? One might also wonder what the lower size limit is for micro diamonds.

The key issue about the micro–macro relationship is whether their distributions are uniquely interrelated and to what extent the macro relationship can be predicted from the micro distribution. The relevant parameters of the macro-frequency distribution that relate to ore grade are:

- the point at which it departs from the linear (micro) relationship;
- the degree of curvature (A and B coefficients of the quadratic expression);
- the ‘height’ of the curve (C coefficient of the quadratic expression).

It has been found that for two deposits having very similar micro distributions, the first two parameters above can be quite different. So an explicit grade determination cannot be made purely from a micro distribution; however, if the size distribution is known (for example from a sample from the same deposit), then the grade can be estimated if it is assumed the size distribution does not vary within the deposit. In the absence of any other measurements, the analysis of micro size frequency distributions can be useful, and with analysis of further deposits, it is hoped that further factors will be found that enable a more accurate estimate of macro diamond distributions and grade.

The population of micro diamonds from deposits which have been subjected to resorption or dissolution in the kimberlite or lamproite magma would be expected to be severely depleted. Removal of only a sub-millimeter layer would destroy most of the micro diamonds, while some coarser diamonds would be reduced in size to become micro sized. The relatively low population of coarser grain diamonds compared to micro diamonds explains why deposits such as at Ellendale in Western Australia have extremely low micro diamond occurrences. Modelling the removal
of a constant layer thickness across all sizes of a population having a (linear) distribution typical of micro diamond populations shows that the resultant distribution conforms to a quadratic relationship. Interestingly, the addition of a constant layer thickness to a quadratic distribution characteristic of macro diamonds transforms the distribution into a linear relationship.

4. Diamond counts and ratios

Micro diamond results are commonly expressed by two values; (1) the quantity of diamonds recovered for a measured host rock weight and (2) the ratio of the quantity above and below 0.5 mm. The interpretation of these values is paramount and is not explicitly provided in reports, with different analysts using different criteria to assess the results. Furthermore, the uncertainty errors in the values are rarely supplied.

Neither the total number of micro diamonds recovered from a host rock sample nor the ratio of micro to macro diamonds is useful in isolation. The reason is best illustrated in Fig. 3, which shows two hypothetical distributions associated with a high and a low grade deposit. While one line exhibits a higher stone count, it is in fact associated with a lower grade by virtue of the micro/macro ratio.

If it is accepted that micro/macro ratios are significant, then it is important to realise the statistical uncertainties in any figure derived from such data. An appreciation of the impact of low stone counts is shown in Fig. 4, where the expected micro/macro ratio has been simulated for a particular distribution.

The oscillations occur where the quantity of macro diamonds is low and so each additional stone makes a significant change in the ratio. In order to remove the errors from this traditional approach, a better parameter is to either express the ratio indirectly as the gradient \( M \) of the size distribution or to derive a corrected ratio. A corrected ratio can be derived from the frequency distribution, which also enables application of confidence levels (CL) and correction of data relating to recovery losses. Fig. 5 shows an example of a micro diamond frequency curve and the associated macro/micro ratio.

The benefit of a frequency relationship expressed by two parameters defining a line is that the second parameter, \( K \), corresponds to the quantity of diamonds usually reported in an analysis. Using more complex statistical techniques (Downing and Clark, 1997), the standard error for the coefficients can be calculated, which can then be translated into standard errors for the micro/macro ratio.
With a suitably expansive collection of data, it may be conceivable to generate criteria linking the linear coefficients, $M$ and $K$, for the micro SFD and the likely grade, as shown in Fig. 6.

The inclusion of further parameters may provide better estimates of grade, such as; the MSS within sieve sizes, discriminating between broken and single crystals, and using geological indicators.

5. Macro diamond populations

Where the recovery of diamonds is sufficient to yield appreciable quantities of macro diamonds, there is scope to generate far more accurate size frequency distributions and grade calculations. One aspect which this paper does not cover is the variability of grade within a deposit.

As mentioned earlier, the macro diamond SFD has a quadratic nature, and for a single population can be expressed as:

$$\log(\text{freq}) = A \log_{10}(\text{MSS}) + B \log_{10}(\text{MSS}) + C,$$

where $A$, $B$ and $C$ are constants (quadratic coefficients).

A few hundred carats of size greater than about 0.02 ct is sufficient to provide sufficient data for a grade determination with an uncertainty of less than 10%. Fig. 7 shows a plot for a 500-carat sample from a particular bulk sample. The smallest size has been omitted from the trendline, as it clearly represents a recovery loss. The uncertainties (error bars) are based on 95% confidence limits using Poisson
distributions. Note the low uncertainty in frequencies of the smaller sizes.

6. Importance of geology in micro-diamond analyses

An understanding of SFDs is fundamental to the economic evaluation of a diamond resource but the role of geological effects on a SFD is also an important factor to consider. Diamonds occur in a matrix of diamondiferous volcanic, pyroclastic and epiclastic rocks, as inclusions in juvenile clasts and in some mantle xenoliths. In diamondiferous hypabyssal rocks, diamond occurs as a xenocryst phase along with other diamond indicator minerals derived from the lithosphere and mantle. Diamondiferous volcanic rocks have collected their contained diamonds either during formation or during eruption to the Earth’s surface. The diamonds included in any volcanic event may be from a single zone or sourced from a number of diamondiferous zones on the way to the surface. The diamonds in each zone may have similar characteristics but each zone would be different depending upon its geological history.

Diamond size distributions in economic diamond deposits are usually log-normal in nature and this is a size distribution seen in many geological environments. The SFD of any deposit is probably a mix of a number of SFD from diamondiferous zones sampled by the erupting volcanic host. The key question in relating micro diamonds to macro diamonds is—are the diamonds related? The complexities involved with the interpretation of diamond growth will probably always make this question difficult to answer. For practical purposes, the genetic relationship between micro diamonds and macro diamonds is not important. What is important is whether the relationship between the SFDs of micro diamonds and macro diamonds is constant in a deposit that is being evaluated.

During eruption and/or emplacement of diamondiferous volcanic rocks, the diamonds behave as a normal component of the rock and are subject to the physical laws of nature as they affect all other parts of the volcanic rock. Of particular importance is the role of sorting within the erupting volcanic rock. Epiclastic sorting has been recorded in the Mwadui pipe and has significantly increased the diamond grade from that of the intruded primary kimberlite (Stiefenhofer and Farrow, 2003). Diamond sorting during volcanic eruption processes has not been documented in the literature but it must occur if the diamonds are present as particles liberated from the host volcanic rock. Volcanic rocks of massive texture (e.g. the tuffisitic kimberlite breccias) are unlikely to exhibit diamond sorting, whereas well-bedded units will show the effects of sorting processes.

Sorting processes must be understood if evaluation programs are using micro diamonds to assist in directing exploration sampling. Sorted fine-grained units may only contain small diamonds and, although having a high micro diamond count, would not necessarily return a significant macro diamond grade when bulk sampled. If graded units are present, then any diamond sampling must take account of the unit thickness and ensure the samples collected are representative of the unit as a whole. The results obtained in targeting coarser grained units in small selective samples may return reduced micro diamond counts but such units have the potential to contain large diamonds.

7. Average diamond values

By combining the size distribution with valuation data, it is possible to gain a better estimate of the average price for the diamonds in the deposit. This exercise requires a relationship between diamond price and diamond size. A valuer can provide estimates of the price for different size categories; however, these estimates have statistical limitations from low diamond counts in larger sizes. Yet, these larger sizes can contribute significantly to the overall price.

The effect of size categories having low diamond counts is that generally the valuation for those categories will be less than that obtained in production. This discrepancy is because the price frequency distribution for a size category is significantly skewed, with only a small proportion of high value diamonds raising the average price substantially. It is not unusual for 80% of the diamonds in a size class to have a value below the average value for that size. In these instan-
ces, it will be appreciated that for low stone counts, say less than 10, there is a high likelihood of only the sub-average value diamonds being represented. Plotting the average value of each size class as a function of the average weight for each class will show errors arising from low representation. For large volumes of diamonds, the value–size relationship plotted logarithmically is generally linear, as seen in Fig. 8. On closer inspection, there are two linear regions for this deposit, however, in the absence of sufficient quantities of diamonds to be confident of this structure, reduction to a single line is useful for estimation purposes.

Having derived a relationship between size and price, it is possible to assign corrected prices to those supplied by a valuer. Applying these prices to a frequency distribution enables an expected production scenario to be modelled, thus providing a more accurate estimate of the overall $/ct price for a deposit.

8. Conclusions

The size frequency curve for diamonds ranging from micro to macro sizes comprises both a linear portion and a quadratic portion. Total diamond counts and the ratio of micro to macro diamonds as an indicator of grade can be misleading as the values are very dependent on the volume of diamonds recovered and the efficiency of recovery for the smallest sizes.

It is believed that an explicit method of determining the grade of commercial (macro) diamonds on the basis of the micro diamonds is not achievable, but useful indications of the grade can be gained from the micro size frequency distribution and the coefficients defining its linear relationship. The approach of using distribution plots combined with other morphological or geological parameters may offer a more accurate indicator of grade.

The macro diamond frequency distribution conforms well to a quadratic relationship, allowing extrapolation to large diamond sizes. Expected average prices for large diamonds can be gained from extrapolations of price–size relationships, which, when combined with size frequency expressions, provide more accurate estimates of average diamond price than that of only the recovered diamonds.

There are no particular quantities or volumes of diamonds that must be recovered in order to estimate grade or value; however, the larger the quantities or volumes involved, the lower the uncertainty of any derived values. It is therefore important that any derived values for say micro/macro diamond ratios, grade or value be accompanied by an uncertainty figure obtained by statistical approaches.

Understanding the geological processes at work in any diamond deposit is also key for the correct application of micro diamond analysis and in prioritising exploration activities.

References


