Estimation of commercial diamond grades based on microdiamonds: a case study of the Koidu diamond mine, Sierra Leone

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Introduction

Given the diversity of natural diamond populations, the relationships between microdiamonds (mostly < 0.5 mm diameter) and commercially relevant larger diamonds (macrodiamonds; mostly > 1 mm diameter) are likely complex and variable. Nonetheless, microdiamonds have been used for more than four decades as a basis for evaluating the grade of primary diamond deposits (Deakin and Boxer, 1989; Steifenhoffer et al, 2016). This has largely demonstrated that, under appropriate conditions, for any given kimberlite unit a systematic relationship can typically be defined between the concentration (number of stones per unit mass of kimberlite) of microdiamonds and the grade (weight of diamond per unit mass) of macrodiamonds. This reflects the fact that, on scales relevant to mining, many kimberlite units are homogeneous with respect to their juvenile components (i.e. those present in the kimberlite magma prior to emplacement). Thus the diamond size frequency distribution (SFD), representing the proportions of diamonds in different size fractions, is broadly constant within a given unit. Diamond size frequency relationships do however vary considerably between different kimberlite units and in many cases are not predictable from microdiamond data alone. Therefore, reliable application of microdiamond-based approaches for quantitative estimation of macrodiamond grade requires: accurate definition of the nature and extent of kimberlite units present; representative microdiamond and macrodiamond data for a portion of each unit being estimated; and confirmation that the SFD of diamonds is constant within each unit. If these conditions are satisfied, macrodiamond grade can be estimated based on microdiamond data combined with the calibrated ratio of microdiamond to macrodiamond content.

This contribution documents application of a microdiamond-based approach to estimation of the grade of the Pipe 1 kimberlite at the Koidu mine in Sierra Leone. Pipe 1 has been mined on and off since 1962 with the majority of the mining taking place between 2005 and 2007 and between 2012 and the present day. The resource estimate documented here was completed in 2014 and applies to the portion of the deposit between the bottom of the open pit at the time (~ 180 masl) and an elevation of -250 masl.

Geology

Pipe 1 is a small (<0.5 ha), irregular pipe-like body comprised of five main kimberlite units, including pipe-fill coherent kimberlite, three varieties of Kimberley Type Pyroclastic Kimberlite (KPK) and volumetrically minor late-stage intrusions of coherent kimberlite. The four volumetrically dominant kimberlite units are: KIMB1, olivine macrocryst- and granitoid xenolith-rich, coherent kimberlite; KIMB2B, very olivine macrocryst-poor, granitoid xenolith-rich KPK; KIMB3, KPK similar to KIMB2B but characterised by the presence of dolerite xenoliths, and autoliths of coherent kimberlite (possible KIMB1) and KIMB4; and KIMB4, medium-grained olivine macrocryst-poor to olivine macrocryst-rich, dolerite microxenolith-rich volcaniclastic to coherent phlogopite kimberlite. The distribution of these units provided the basis for a geological model comprising four domains (Fig. 1). The proportion of country-rock xenoliths varies between and within domains; hence the amount of dilution is a dominant factor controlling diamond grade variability. Petrography and microdiamond results indicate that the diamond SFD is constant within each domain. Furthermore, the massive character of the rocks and results of microdiamond analysis and bulk sampling indicate that, within the four volmetrically dominant pipe kimberlite units, the grade of undiluted kimberlite is constant.

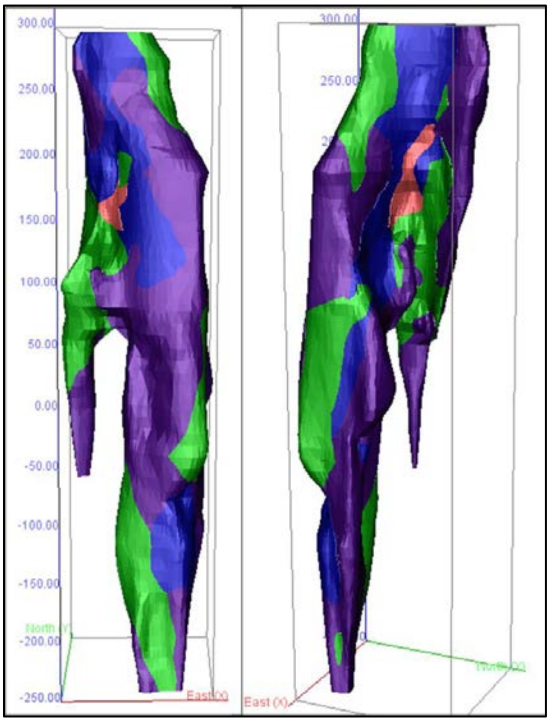

Figure 1. Model of Koidu Pipe 1 kimberlite below 300 masl, looking north (left) and southwest (right). Kimberlite domains are shown in different colours. Purple: K1, dominated by KIMB1; green: K2 dominated by KIMB2B; blue: K3, dominated by KIMB3; red = K4, mixture of KIMB3 and KIMB4.

Methods and evaluation approach

Practical considerations associated with active mining precluded grade estimation using the traditional approach of direct macrodiamond sampling through large diameter drilling. A microdiamond-based approach was therefore applied. The approach is based on: the geological model described above; macrodiamond data from four bulk samples (853 to 1726 tonnes per sample) excavated from each of the main kimberlite units; microdiamond data generated by caustic fusion analysis of 683 well-distributed drill core samples (~8 kg each); and quantitative estimates of the percentage of country-rock dilution, determined by continuous line-scan measurements undertaken on 29 of the 35 core drill holes intersecting the kimberlite in the zone of interest. Macrodiamonds were recovered from the bulk samples by crushing, dense media separation and X-ray diamond recovery using the Koidu production processing plant (1.2 mm bottom cut off). The estimation approach involved calibration of the micro-/macrodiamond relationship using macrodiamond data from the bulk samples paired with representative microdiamond samples of the same material. This relationship was applied to microdiamond stone frequency data (stones per kg) from drill core samples to derive estimates of the average undiluted grade per kimberlite domain. A block model representing the spatial variation in diluted grade was generated from these average domain grades by incorporating an interpolated model of the percentage of country-rock dilution based on the line-scan data.

Results

The results obtained using the above-described approach are summarsied in Table 1 which provides an indication of the variability in grade on a bench (10 m mining level) scale within each of the modelled domains. The overall accuracy of the grade estimates has been assessed based on reconciliation with production data obtained subsequent to the definition of the resource (Fig. 2). The production data are derived from mine records of material processed through the Koidu production diamond processing plant, including total, total stones and carats recovered, source of ore (Pipe 1) and the mining level (bench) from which the material was derived. At the time of writing, reliable records (i.e. representing material sourced almost exclusively from Pipe 1) were available for the portion of the pipe between 160 and 110 masl. From production records, the overall tonnage of material produced from this interval was 620 k tonnes, corresponding with an estimated resource of 561 k tonnes. Possible reasons for the 10% tonnage discrepancy between production records and the resource estimate include minor discrepancies between the modelled and actual kimberlite volume and inclusion of material from the levels immediately overlying and/or underlying the benches to which the production was assigned. The results shown in Figure 2 indicate a very close match between predicted and actual grades on the scale of 10 m benches, indicating that, when supported by a sound geological model and suitable microdiamond and macrodiamond data, the microdiamond-based estimation approach can provide reliable constraints on macrodiamond grade, even in the case of geologically complex bodies such as Koidu Pipe 1.

Table 1. Minimum, mean and maximum bench grades and percentage dilution estimates for each of the Pipe 1 kimberlite domains. The data represent 43 benches (10 m each) between 180 and -250 masl.

Domain	Dilution (%)			Grade (cpt)		
	Min	Mean	Max	Min	Mean	Max
K1	17	27	47	0.41	0.56	0.69
K2	22	45	65	0.16	0.25	0.35
K3	19	27	40	0.32	0.45	0.55
K4	15	26	34	0.47	0.60	0.82

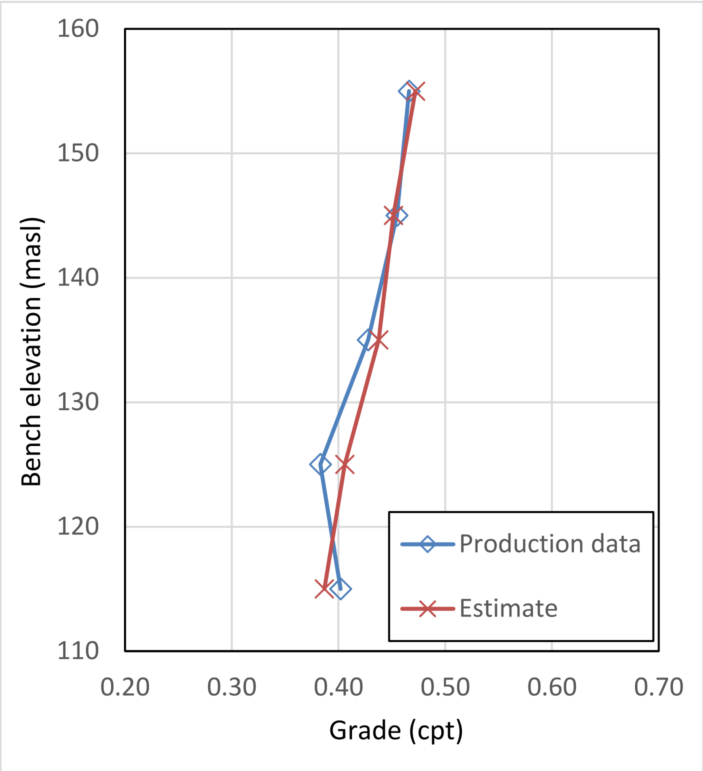

Figure 2. Comparison of bench grades based on production data with those derived from the mineral resource estimate. The comparison applies to the portion of the pipe between 160 and 110 masl.

References

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