DECODING THE DIAMONDS FROM THE AK6 KIMBERLITE

I L Chinn, M A Krug, W P Minnie and CT Rikhotso
DE Beers GROUP EXPLORATION

1. Introduction

The AK6 kimberlite is situated 25 km south of the Debswana Orapa Mine in Botswana and was discovered by De Beers geologists in 1969 during the follow-up of geophysical targets in the Orapa area. The kimberlite was not extensively pursued at the time as the initial bulk sampling indicated it to be of limited size and low grade, factors largely contributed to by the basalt breccia capping. Completion of high resolution integrated geophysical techniques and drill bulk sampling to depth recovered 97 tons of kimberlite during 2003 and 2004, which led to the increased size and grade estimates. Bulk sampling by Large Diameter Drilling (LDD, 23 inch diameter) commenced in 2005; 13 holes were drilled to a cumulative depth of 3,699 m and 689 carats of diamonds were recovered. In July 2006 the De Beers Mineral Resource Classification Committee classified these Phase 1 LDD results at a High Inferred level with an average grade of 24 carats per hundred tonnes (cpht) at a bottom cut-off of +1 mm, and a modeled average diamond value of 150 dollars per carat. A second phase of LDD drilling was initiated in 2006, and bulk sampling by trenching commenced in 2007 in order to deliver a resource estimate at indicated level. An Indicated Resource of 11.1 million carats at an average grade of 22 cpht was declared for the deposit mining lease application lodged in 2007.

2. Kimberlite geology

The geological model (see Figure 1) for the tri-lobate AK6 kimberlite constructed by Opperman[1], using data from 44 percussion boreholes, 23 pilot boreholes, 31 large diameter drill holes and 51 delineation boreholes, was updated by Tait and Maccelari[2]. The AK6 kimberlite has a subcrop surface area of 4.4 hectares at 1012 metres above mean sea level. Analyses of mantle zircons yielded indistinguishable ages of 88 ± 5 Ma, 93± 3 Ma, and 93 ± 2 Ma for the North, Centre and South lobes respectively[3,4]. However, cross-cutting stratigraphic relationships identified during core logging indicate that the Centre lobe erupted prior to the volumetrically dominant South lobe[5].

Broad similarities are recognised between the North and Centre lobes in terms of shape, petrographic, geochemical and geo-metallurgical signatures, whereas the South lobe exhibits distinctly different characteristics including low levels of alteration[6]. Kimberlite rocks from the North and Centre lobes appear to be of volcaniclastic origin, with macroscopic and microscopic scale heterogeneity[6]. Both the North and Centre lobe kimberlites appear to have contained significant void space which is now filled with carbonate minerals[7]. The South lobe exhibits localised lithic clast orientation with possible layering of olivine macrocrysts and crustal fragments, and appears to be more clastogenic in origin, with welded pyroclasts and lower original porosity[6,7]. Rare fresh monticellite has been observed within the groundmass of kimberlite from the South lobe.

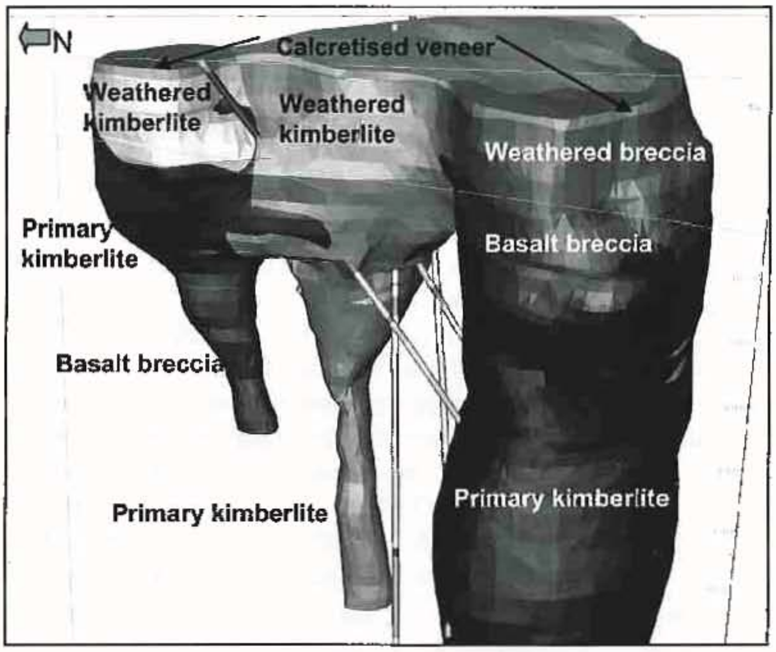

Figure 1: Three dimensional model[2] of the AK6 kimberlite, looking northeast, showing the North, Centre and South lobes which increase in size respectively. The boreholes shown between the Centre and South lobe intersected additional kimberlite dykes. Modelled depth is to 400 metres.

3. Diamond descriptions

Diamond researchers have long debated the effect of kimberlite magma on diamonds, and the timing of diamond resorption and etching. Experiments[8] have indicated that the presence of a free fluid phase promotes the formation of dodecahedral morphologies via resorption, and also that CO_2-rich and water-rich fluids produce different surface textures.

Diamonds recovered during the bulk sampling programme provided a unique opportunity to relate their characteristics to the host kimberlite facies. The diamond recoveries were recorded in 12 metre sample intervals from 23 inch diameter LDD boreholes, allowing for correlation with drill logs from pilot holes in close proximity. The colour, morphology and surface features of 190 diamonds from LDD011 (North Lobe) were described, and compared with results from 178 diamonds from LDD007 (Centre lobe) and 193 diamonds from LDD006 (South lobe). The diamonds studied range in size from the +5 to +19 DTC sieve classes, corresponding to circular apertures of 1.83 and 6.35 mm respectively.

3.1. Colour

The presence of impurities (such as substitutional nitrogen) and/or defects in the diamond lattice may impart a colour to the diamond, and provide information pertaining to the diamond growth and mantle residence conditions. The presence of singlysubstituted nitrogen atoms results in amber or yellowish-green colour, whereas the presence of nitrogen aggregates may impart no or pale 'Cape' yellow depending on the configuration of the nitrogen[9]. In this study very pale yellow diamonds were described as colourless. The broad similarity of the colour distributions of diamonds from the North, Centre and South lobe kimberlites shown in Figure 2 suggests that the kimberlites sampled diamonds from diamond host rocks which had experienced similar diamond growth and mantle residence conditions.

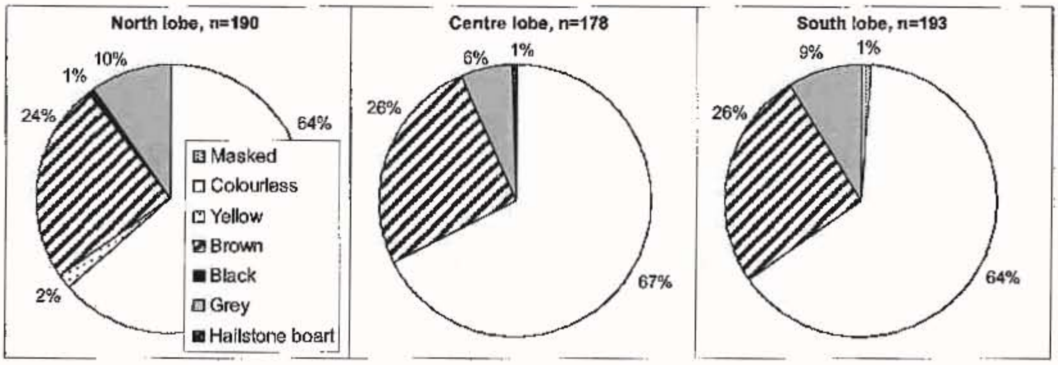

Figure 2: Colour distribution of diamonds from the North, Centre and South lobes of the AK6 kimberlite. Note that very pale yellow diamonds were included with the colourless stones.

3.2. Morphology

Figure 3 illustrates the primary morphology of diamonds from the three kimberlite lobes. The North and Centre lobes show elevated levels (93% and 83% respectively) of rounded dodecahedra, formed by mainly by dissolution of octahedra, although a minor proportion were derived from resorption of cubic or cubo-octahedral morphologies. In contrast, octahedral morphologies comprise 74% of the diamonds from the South lobe, with only 23% classified as rounded dodecahedra.

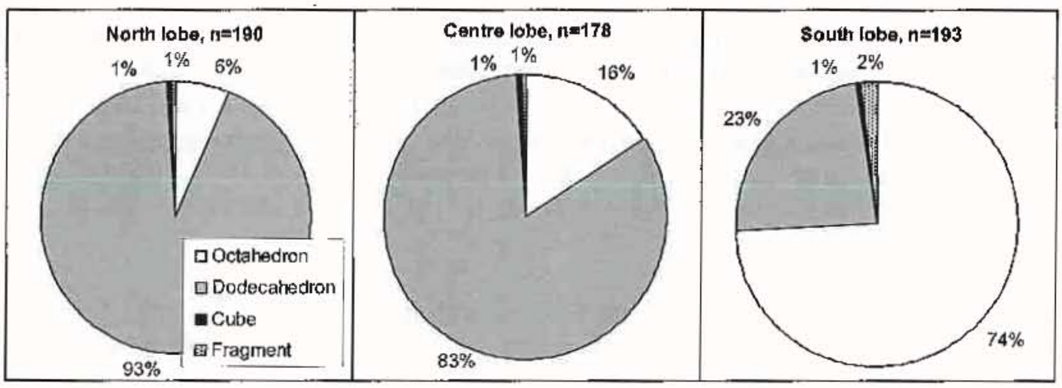

Figure 3: Primary morphology distribution of diamonds from the North, Centre and South lobes of the AK6 kimberlite.

Fine lamination lines caused by plastic deformation of the diamond lattice were identified on 47% and 42% of the diamonds from the North and Centre lobes respectively. The South lobe diamonds record lower levels (7%) of plastic deformation. This is not an artefact of the higher abundance of dodecahedra in the North and Centre lobes (lamination lines are more readily identified on dodecahedral surfaces) as the percentage of dodecahedra with fine lamination lines was calculated at 51% and 50% for the North and Centre lobes, and only 29% for the South lobe.
Trigonal etch pits were identified on 97% of the South lobe diamonds, in comparison with only 66% and 56% of the North and Centre lobe diamonds. Similarly, knoblike asperities, which are a common feature found on diamonds within mantle xenoliths[10], are common on diamonds from the South lobe (57%), but are scarce in the North and Centre lobes (one and two instances respectively). Terraces formed by the resorption of octahedral growth layers were noted on 38% and 36% of the North and Centre lobe diamonds, but only on 5% of the South lobe diamonds which is a reflection of the lower prevalence of dodecahedral morphology among the diamonds from the South lobe. Diamonds with corrosion sculpture increase steadily in abundance from the North (2%) to the Centre (30%) and South Lobe (45%), whereas the percentage of fine frosting decreases steadily from 25% to 16% and 8% respectively.

4. Geological interpretation of AK6 diamond characteristics

When evaluating the differences between the diamonds from the three kimberlite lobes, it is important to attempt to place the features in context, depending on their origin and relative timing. Certain features, e.g. the paragenesis of mineral inclusions, will be defined by the peridotitic or eclogitic growth medium. Conditions such as the prevailing temperature and pressure during crystallisation will have an effect on the crystal form of the diamonds; favouring octahedra, cubo-octahedra or cubic morphologies. Other factors such as redox conditions and the level of carbon supersaturation, may also play an important role in the crystallisation mechanism (layered or fibrous growth) and resulting morphology of diamonds. Episodes of deformation and oxidation impose characteristic surface features which can assist in decoding the sequence of events recorded by the diamonds.

A few inclusions (chrome spinel and orange garnet) visually identified in the diamonds indicate that diamonds sampled by the AK6 kimberlite magmas grew in both peridotitic and eclogitic lithologies. Rare nitrogen-free Type II diamonds have been identified in the AK6 kimberlite, particularly in the South lobe which has been more extensively sampled. The paragenetic origin of these diamonds has been the subject of much debate[11], which is hampered by the absence of silicate or oxide inclusions in these diamonds.

The higher levels of plastic deformation noted in the diamonds from the older North and Centre lobes may imply that the majority of the deformation took place during formation of conduits for the kimberlite magma prior to eruption. Immediately prior to and/or during eruption of the North and Centre lobes, a large proportion of the diamonds were resorbed to dodecahedral morphologies in the presence of a free fluid phase which may have facilitated the eruption mechanism. The diamond resorption resulted in a coarsening of the size frequency distribution (by destruction smaller diamonds) in comparison with the diamonds of the South lobe.

The eruption of the South lobe appears to have occurred at higher temperatures[6] than the North and Centre lobes. The abundance of knoblike asperities suggests that partial graphitisation of diamonds in fluid undersaturated conditions occurred, rather than resorption to form dodecahedra. The necessary conditions could have been created by the rapid accumulation of welded pyroclastic kimberlite. The presence of groundmass monticellite in the South lobe may be consistent with degassing of CO_2 from the kimberlite magma, following dissociation of CaO and carbonate[12]. The irregular and rough nature of etch features on diamonds from the South lobe is more consistent with CO_2-rich conditions than water-rich conditions which may have been present during eruption of the North and Centre lobe.

5. Conclusions

Geological control on the source of diamonds within a complex kimberlite body allows for meaningful interpretation of the interaction between diamonds and kimberlite magmas. Deformation of diamonds may be related to the formation of conduits for the eruption of the kimberlite magma. In the case of the AK6 kimberlite, deformation levels of diamonds from the younger South lobe appear to be less severe than the North and Centre lobes.

Morphological variations noted in diamonds from the North, Centre and South lobes of the AK6 kimberlite may be explained by relatively late stage processes associated with kimberlite eruption, rather than by sampling of discrete mantle lithologies. The composition, presence or absence of fluid phases associated with the kimberlite magmas has a major effect on diamond morphology and surface features. Subtle differences in diamond size distribution and value may thus be better understood by integration of petrographic and diamond data.

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The Author

Ingrid Chinn, *Principal Specialist – Diamonds*, De Beers

Ingrid joined De Beers Group Exploration in 1998 after completing a PhD under the supervision of Professor John Gurney of the Kimberlite Research Group at Cape Town University. Her expertise is in diamond population discrimination using their physical properties, nitrogen content and speciation, derived from Fourier Transform Infrared analysis. During her time with De Beers she has worked on many prospecting and applied research projects. She has been involved in diamond recovery at the Group Exploration Macrodiamond Laboratory in Johannesburg, and during the processing of bulk samples from the AK6 kimberlite in Botswana she was responsible for diamond characterisation. Her current focus is on applied research and development projects and providing assurance on diamond analyses and data.