10IKC-222

UTILIZATION OF OLIVINE MACROCRYST GRAIN SIZE AND ABUNDANCE DATA AS A PROXY FOR DIAMOND SIZE AND GRADE IN PYROCLASTIC DEPOSITS OF THE ORION SOUTH KIMBERLITE, FORT À LA CORNE, SASKATCHEWAN, CANADA

S. Harvey, G. Read, B. DesGagnes, M. Shimell, J. Danoczi, B. van Breugel, L. Fourie, and A. Stilling
Shore Gold Inc., 300 – 224 4th Avenue South, Saskatoon, SK, Canada S7K 5M5

INTRODUCTION

The Fort à la Corne (FalC) kimberlite field, with approximately 70 kimberlite bodies, is situated in east-central Saskatchewan, Canada, 60 km east of the city of Prince Albert. The FalC kimberlites are 106-94 Ma in age (Leckie et al., 1997; Zonneveld et al., 2004; Harvey et al., 2009; Kjarsgaard et al., 2009) and erupted contemporaneously with Cretaceous Mannville Group and Colorado Group sedimentation along the eastern margin of the Western Canadian Sedimentary Basin.

The FalC kimberlites consist primarily of volcaniclastic deposits which are interstratified with Lower Cretaceous continental, marginal marine and marine sediments. The ca. 100 Ma Orion South kimberlite complex is located near the south-eastern extremity of the main FalC trend and contains well preserved primary volcaniclastic kimberlite deposits.

The Orion South kimberlite complex represents one of the largest kimberlite deposits in the world (Scott Smith et al., 1998). Based on a zero metre kimberlite edge, Orion South has an interpreted area of 358 hectares corresponding with a kimberlite tonnage in excess of 350 million tonnes (Harvey et al., 2009). The Orion South kimberlite is a multi-phase cone-and-crater volcaniclastic complex made up of shallow craters and variably shaped cones/rings of debris, fed by narrow conduits that extend hundreds of metres below the paleo-surface (Harvey et al., 2009). Mapping (core and underground) has identified that the Orion South kimberlite is dominantly composed of variably-sorted pyroclastic and epiclastic deposits. Extensive mini-bulk sampling through large-diameter drilling and underground bulk sampling has indicated a wide variation in diamond size and grade (carats per hundred tonne (cpht)) across the kimberlite complex, both between kimberlite units and within individual units.

In general, the diamond grades of the kimberlite units are relatively low, with the most extensively tested kimberlite unit, the Early Joli Fou (EJF) unit, having an underground bulk sample recoverable grade of the order of 18 cpht. In contrast, the diamond quality and coarse size distribution results in a modeled diamond price of US$249 per carat (Shore Gold News release dated July 28, 2011).

In this contribution we consider the olivine, and by proxy, the diamond, distribution throughout the largely pyroclastic deposits of the Orion South kimberlite complex. Previous contributions regarding olivine distributions in kimberlite have utilized quantitative data to examine the olivine distributions in great detail (e.g. Field et al., 2009; Scott Smith and Smith, 2009; Moss et al., 2010). This contribution summarizes a semi-quantitative method of kimberlite constituent data acquisition and analysis that can be utilized as a tool towards diamond grade estimation.

VOLCANICLASTIC KIMBERLITE DEPOSITS

As the vast majority of the Orion South kimberlite deposits are considered volcaniclastic, sorting has played a pivotal role in grain size variation. These sorting mechanisms resulted in both vertical and lateral grain size variation and abundance variation in the individual kimberlite constituents. Physical sorting processes would have operated on the scale of individual mineral grains and is likely the result of aerodynamic processes during the initial pyroclastic eruption and syn-eruptive deposition. Further hydrodynamic sorting during subsequent reworking occurred locally. As olivine (forsterite) has a relatively similar density to diamond (3.3 versus 3.5 g/cm^3) and is the dominant component in the deposits it is considered to be a good proxy for diamond (e.g. Field et al., 2009 and Moss et al., 2010).

At Orion South, both olivine macrocryst grain size and olivine macrocryst abundance are considered important when evaluating the volcaniclastic deposits and the associated diamond size and grade variation. In general, the Orion South kimberlite deposits with a high average olivine macrocryst grain size and high olivine macrocryst abundance tend to have higher grades than those deposits with a high average grain size but low olivine macrocryst content. In detail, analysis of the olivine data coupled with diamond size data from bulk and mini-bulk sampling indicates that there is a positive correlation between olivine size and abundance with diamond size and grade. This correlation can be used not only between units of kimberlite within the complex but within individual units resulting in more robust geological and mineral resource models.

Based on detailed core logging and supporting data (e.g. chemistry, geophysics; Harvey et al., 2009) the Orion South kimberlite complex has been subdivided into six kimberlite units and minor reworked equivalents. The volumetrically important units include (from oldest to youngest) the Pense, EJF and Late Joli Fou (LJF).

Pense Kimberlite

The first major eruptive event on Orion South resulted in kimberlite being deposited onto Pense Formation sediments (Harvey et al., 2009). The crater base is cut into the pre-eruptive paleosurface and into Mannville Group sediments. The Pense kimberlite is a fine- to locally medium-grained, matrix-rich, poorly-sorted, massive to weakly-bedded volcaniclastic lapilli tuff that is remarkably consistent both laterally and vertically. The matrix-rich texture of the unit and its massive appearance are in distinct contrast to the subsequent EJF unit. Xenoliths are rare within the Pense, while juvenile pyroclasts are also rare (generally <5%). Locally, distal deposits exhibit thin (0.1 to 0.5 m) planar bedding. The upper surface exhibits considerable and variable relief with a central mound (volcanic cone) that has 87 m of positive relief relative to the Pense Formation paleo-surface. The thickest intersection recovered 220 m of Pense kimberlite, while it thins to near zero over 700 m laterally.

EJF Kimberlite

Vent distal deposits of the volumetrically dominant kimberlite unit in Orion South were laid down directly on early Joli Fou Formation sediments. Proximal deposits were deposited on Pense kimberlite and Mannville Group sediments, the latter due to erosive down cutting of the pre-eruptive paleosurface during initiation of the EJF eruptive cycle. There are two centres of thick EJF accumulation in the north-west and the south-east sections of the Orion South kimberlite complex (Harvey et al., 2009).

In stark contrast to the previously deposited Pense kimberlite, the EJF is olivine rich to the point of commonly being nearly olivine clast supported. These EJF deposits are fine- to coarse-grained, olivine pyroclast-rich, poorly- to moderately-sorted, volcaniclastic lapilli tuff to tuff breccia. The unit is interesting in that pyroclastic sorting has caused strong subdivision of coarser and finer constituents on a variety of scales. This sorting process has greatly affected average olivine macrocryst grain size and abundance distributions and, simultaneously, diamond grain size and abundance distributions. The deposits consist of multiple normally graded beds (Fig. 1) with poorly sorted, medium- to coarse-grained bases and moderately-sorted, finer-grained tops that collectively form a locally preserved fining-upward succession (Harvey et al., 2009). This succession is only locally preserved as the upper portions of the unit have been removed by subsequent eruptive events and by glacial erosion. Individual beds are generally between 0.5 and 10 m thick (Fig. 1 and Fig. 2), although thicker beds (up to 30 m) have been observed.

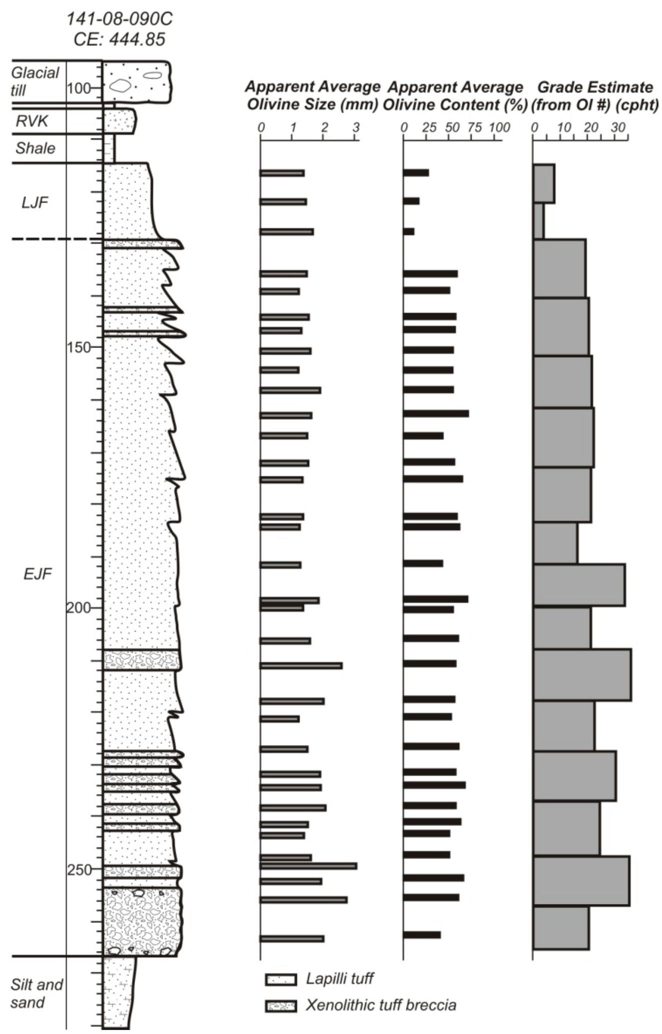

Fig. 1. Simplified strip log of drill hole 141-08-090C along with line scan-generated apparent average olivine macrocryst size and content along with estimated grade based on olivine number and its relationship to diamond grade.

In contrast to other Orion South units, the EJF is locally composed of xenolith-rich tuff breccia (Fig. 2). The 0.5-10 m thick xenolith-rich horizons typically form the bases of normally graded beds that fine upward into olivine-rich volcaniclastic tuff and lapilli tuff. These xenolith-rich bases are more common in the lower part of the EJF stratigraphic pile. Towards the top of the EJF succession and in distal areas, the normally graded deposits typically do not have xenolith-rich bases (Kjarsgaard et al., 2006, 2009).

Fig. 2. Example of a 7 metre normally graded bed with a coarser xenolith-rich base fining-up to a very fine-grained xenolith-poor top (from 140-06-058C: from 132.01 to 136.79m).

Late Joli Fou Kimberlite

A very fine- to fine-grained, moderately-sorted, massive to weakly planar bedded, olivine-rich volcaniclastic kimberlite of late Joli Fou equivalent age directly overlies EJF deposits. In contrast to the bulk of the EJF deposits, the LJF tuffs are olivine macrocryst-poor and phenocryst-rich, while juvenile pyroclasts are rare to absent. Proximal deposits are thick, but thin dramatically over a short lateral distance.

SEMI-QUANTITATIVE DATA ACQUISITION

Detailed semi-quantitative measurements of kimberlite constituents are acquired utilizing a combination of detailed line scan (DLS) and a coarse area scan (CAS). The DLS method measures all sub-10 mm constituents falling along a 10 cm line on cut core and slabbed underground hand samples using a binocular microscope. Each constituent (e.g. olivine, juvenile pyroclast, garnet, crustal and basement xenoliths) along the line axis greater than, or equal to, 1 mm is measured while all constituents less that 1 mm (including olivine) are considered matrix. Essentially, utilizing this method, only olivine macrocrysts are quantified, while olivine phenocrysts are considered to be part of the matrix. The 1 mm cut-off was utilized as only diamonds greater than 1 mm were recovered in the sampling programs and diamonds less than 1 mm are considered to have little commercial value. Constituents greater than 10 mm are avoided in scan positioning, as these data are captured within the CAS. The CAS method measures all 10 mm plus-sized constituents along the cut face of the core surface or an underground wall face over a 1.0 to 1.5 m interval. The DLS sample falls within the larger CAS interval. For core analysis, the line and areas scans are generally spaced from 3 to 15 meters depending on bedding thicknesses. The CAS and DLS location best represents the average texture and grain size from the geologically-defined sub-interval. Within the DLS dataset, of the measured non-matrix constituents, olivine comprises over 70 percent of the total measurements. Over 25,000 olivine grains were measured from the EJF on Orion South.

As the DLS method only measures along the line axis, the measurements are not along constituent axis and, as such, will underestimate the true size of the constituents. Measurements do, however, allow comparative analysis between kimberlite units and within individual kimberlite units.

RESULTS

Based on the data generated from the DLS method, the olivine macrocryst size distribution between kimberlite units (Fig. 3) indicates that, in general, the EJF unit is the coarsest followed closely by the Pense unit. In contrast, the LJF has a much finer olivine macrocryst size distribution. Importantly, although the Pense and EJF kimberlite units have a similar olivine macrocryst size distribution, the olivine contents are very different. In figure 4, the cumulative olivine macrocryst content of the three main units is defined. On average, the EJF has the highest olivine macrocryst content, while the Pense is significantly depleted, and the LJF has even lower olivine macrocryst content relative to the other units.

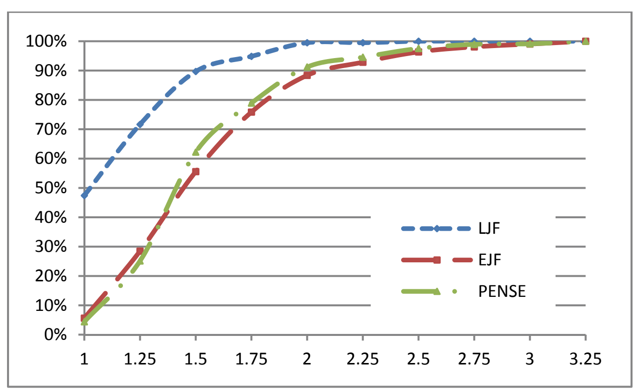

Fig. 3. Cumulative olivine macrocryst size (mm) distributions for the Pense, EJF and LJF units (grouped in 0.25 mm size classes).

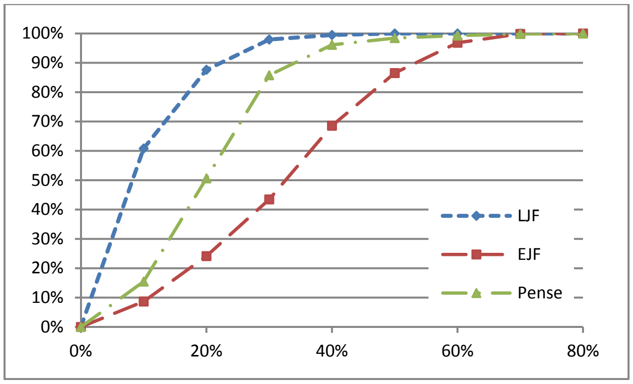

Fig. 4. Cumulative olivine content (%) comparison for the Pense, EJF and LJF units (grouped in 10% classes).

Utilizing the underground bulk sampling and large diameter drilling mini-bulk batch sample data, the cumulative diamond size distribution for the three main units can be seen (Fig. 5). Corresponding to the olivine macrocryst size and perhaps the olivine macrocryst content distribution, the diamond size distribution between kimberlite units (Fig. 5) indicates that the EJF unit is coarsest with the Pense and LJF being finer overall.

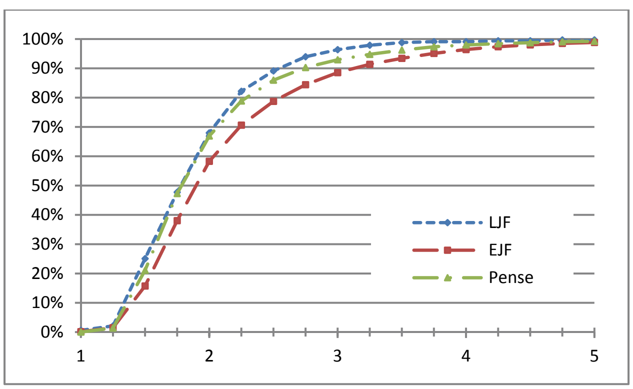

Fig. 5. Cumulative diamond size (mm) distributions for the Pense, EJF and LJF units (grouped in 0.25 mm size classes).

Olivine size and content variations within individual kimberlite units can also be analyzed and quantified. The EJF kimberlite is dominated by multiple graded beds within an overall fining-up sequence. Importantly, the overall fining-up succession is not simply a function of depth from surface or elevation above sea level but it is a function of elevation above the base of the EJF contact. As the basal EJF contact is largely controlled by the topographically irregular upper surface of the Pense unit (Harvey et al., 2009), very coarse EJF material can be found at very shallow depths where the Pense high is in close proximity to the base of till. As such, it is best to look at the overall EJF fining-up succession in terms of meters above the basal EJF contact. From figure 6 the overall fining-up succession is clear when viewed as elevation above the basal contact. Notably, there appears to be a distinction in average olivine macrocryst size at an elevation above the contact of approximately 100 m. Below this level the fining-up progression is pronounced, while above this level the fining-up is less distinct. If a similar grouping of mini-bulk EJF batch samples are detailed (Fig. 7) in terms of meters above the basal contact, the overall fining-up succession is notable in the mean diamond size. As with the olivine data, a distinct break at 100 m above the basal contact is notable.

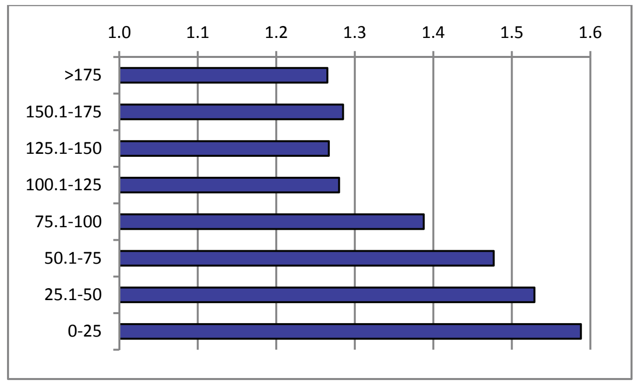

Fig. 6. Summary of average EJF olivine macrocryst size (mm) with respect to elevation (m) above the basal EJF contact.

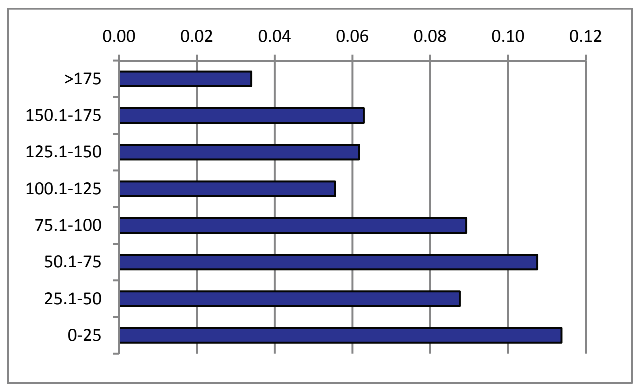

Fig. 7. Summary of EJF mean diamond size (carats per stone) with respect to elevation (m) above the basal EJF contact from large-diameter mini-bulk samples.

As there appears to be a strong relationship between olivine size/content relative to diamond size/content a grade proxy based on olivine size and content has been developed for Orion South. Olivine data from large-diameter drill pilot core holes along with olivine data from underground samples were coupled with large-diameter drill mini-bulk and underground batch samples to develop a trend line relationship between the two datasets. Utilizing the formulation generated from the relationship, a grade estimate throughout the Orion South core dataset was utilized. This allowed grade estimates across the entire kimberlite which, importantly, includes areas where mini-bulk sampling had not been completed.

From the estimation work, it is apparent that, on average, the deposits that have a relatively high average olivine macrocryst size coupled with high olivine macrocryst content have the highest diamond grade. This appears to be most applicable to EJF unit as a whole (see Fig. 1 and Fig. 8). In contrast, even with a relatively high average olivine macrocryst size, the Pense has a lower diamond grade. This may be due to the relatively low olivine macrocryst content. Conversely, deposits with both a low average olivine macrocryst size and low olivine macrocryst content have the lowest grade potential. This appears to be the case for the LJF kimberlite unit (Fig. 1 and Fig. 8).

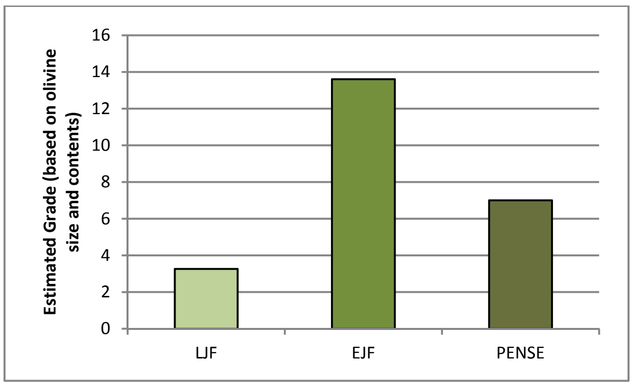

Fig. 8. Grade estimation of the main kimberlite units on Orion South based on correlation of olivine number and large diameter drill mini-bulk samples.

The presence of large and abundant olivine macrocrysts in pyroclastic kimberlite does not guarantee the presence of diamond. If diamonds are present in the pyroclastic kimberlite, however, olivine macrocryst abundance and size can be used as a proxy for diamond grade and size. Pyroclastic kimberlite olivine macrocryst abundance and size is controlled by volcanogenic processes and, therefore, the use of olivine as a proxy for diamond applies to both peridotitic and eclogitic diamond populations that may be present in the kimberlite eruption.

It can be concluded that both olivine and diamond size and abundance vary greatly across the Orion South kimberlite complex. This is apparent both between kimberlite units but also within individual units. It can also be concluded that pyroclastic sorting processes have played a significant role in concentration and dilution of olivine macrocrysts and diamonds.

References

Field, M., Gernon, T. M. Mock, A., Walters, A., Sparks, R. S. J., and Jerram, D. A. (2009) Variation in olivine abundance and grain size in the Snap Lake kimberlite intrusion, Northwest Territories, Canada: A possible proxy for diamonds; Lithos, v112S, p23-35.

Harvey, S., Kjarsgaard, B., McClintock, M., Shimell, M., Fourie, L., Du Plessis, P., and Read, G. (2009) Geology and evaluation strategy of the Star and Orion South kimberlites, Fort à la Corne, Canada; Lithos, v112S, p47-60.

Kjarsgaard, B.A., Harvey, S.E., Zonneveld, J-P., Heaman, L.M., White, D., MacNeil, D. (2006) Volcanic stratigraphy, eruptive sequences and emplacement of the 140/141 kimberlite, Fort a la Corne Field, Saskatchewan. Kimberlite Emplacement Workshop, Saskatoon, Saskatchewan.

Kjarsgaard, B.A., Harvey, S.E., Du Plessis, P., McClintock, M., Zonneveld, J-P., Heaman, L., McNeil, D. (2009) Geology of the Orion South Kimberlite, Fort à la Corne, Canada; Lithos, v112S, p600-618.

Leckie, D.A., Kjarsgaard, B.A., Bloch, J., McIntyre, D., McNeil, D., Stasiuk, L., Heaman, L. (1997) Emplacement and reworking of Cretaceous, diamond-bearing, crater facies kimberlite of central Saskatchewan, Canada. Geological Society of America Bulletin 109, 1000-1020.

Moss, S., Russell, J. K., Scott Smith, B. H., and Brett, R. C. (2010) Olivine crystal size distributions in kimberlite; American Mineralogist, v95, p527-536.

Scott Smith, B.H., Orr, R.G., Robertshaw, P., Avery, R.A. (1998) Geology of the Fort à la Corne Kimberlites, Saskatchewan. 7th International Kimberlite Conference, Cape Town, South Africa, Extended Abstracts vol., 772-774.

Scott Smith, B. H. and Smith, S. C. S. (2009) The economic implications of kimberlite emplacement; Lithos, v112S, p10-22.

Zonneveld, J-P., Kjarsgaard, B.A., Harvey, Heaman, L.M., McNeil, D.H., Marcia, K.Y. (2004) Sedimentologic and stratigraphic constraints on emplacement of the Star Kimberlite, east-Central Saskatchewan. Lithos 76, 115-138.