DEEP INFILL CRATER MODEL FOR LAC DE GRAS KIMBERLITES IMPLICATIONS FOR DIAMOND DISTRIBUTION

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INTRODUCTION

The presence of sedimentary features within many kimberlites of the Lac de Gras field cannot be attributed to classic kimberlite emplacement models. This paper describes four generalized kimberlite lithologies found at great depth in many of these kimberlites, and proposes an emplacement model to account for them. Some implications of the model on microdiamond and commercial size diamond distribution are also discussed.

Before attempting to understand microdiamond and/or commercial size diamond distribution in a kimberlite pipe, one must first consider the mode of emplacement of the kimberlite body. Sedimentary processes rather than purely volcanic processes dominate many kimberlites in the Lac de Gras region.

Generally, the Lac de Gras kimberlites are small in diameter and often lack large tuffisitic kimberlite and tuffisitic kimberlite breccia lithologies. In fact, there are examples in the Lac de Gras field where small volume pipes exhibit crater lithologies down to depths more than three times their diameter.

The distribution of diamonds in diatreme kimberlite and or hypabyssal kimberlite lithologies is very different from diamond distribution in crater kimberlite lithologies. Understanding these differences is important in economic evaluation of a kimberlite body.

THE LAC DE GRAS KIMBERLITES

In the Lac de Gras kimberlite field a class of pipes exists characterized by small (100 to 300m in diameter) steep-walled bodies with crater facies kimberlite extending deep into the pipe (as deep as 300m to 400m). There are four commonly occurring kimberlite lithologies distinguished on the basis of sedimentary texture. These lithologies are:

Fine grained well sorted kimberlite (FSK) is finely laminated comprising angular kimberlite grains less than 0.5mm set in a fine matrix of clay and serpentine. Grains larger than 0.5mm and up to 1.5mm in size form only 10% to 20% of the rock. This unit is re-worked by mechanical processes which have left most of the grains fragmented, stripped of primary surface features, and showing strong sorting and layering throughout.

Poorly sorted matrix supported kimberlite (PSK) contains variable amounts of kimberlitic grains commonly 0.5mm to 4mm in size and as large as 1.5cm. Mineral grains are intact and bear remnant primary rims. Accretionary lapilli are rare and comprise less than 1% of the rock. As the matrix content increases the beds become irregular and more discontinuous laterally. This unit contains clasts of angular country rock, black irregularly shaped mudstone, and fragmented FSK. Average clast content ranges from 3% to 10% and locally up to 25%. Trace amounts of mantle nodules including eclogite, lherzolite and dunite have been observed.

Coarse grained clast / grain supported kimberlite (CK) contains high concentrations of coarse olivine and other kimberlitic mineral grains ranging in size from 1mm to 20mm. Clasts include irregularly shaped penecontemporaneous mudstone, country rock, kimberlite, and mantle nodules. Accretionary lapilli form up to 1% of the mass. This rock is generally grain/clast-supported with little to no matrix material. Xenoliths range in size from 1cm to 10cm and may form 15 to 70% of the rock.

Mudstone kimberlite (MK) is a very fine-grained fissile, waxy mudstone that occasionally grades into siltstone of kimberlitic affinity. Mudstone kimberlite both overlies and underlies the CK with sharp lower contacts and disrupted upper contacts at the base of CK.

These four kimberlite lithologies have been observed as discrete beds of variable thickness and orientation at depths as great as 300m. The lithologies show great variability within a single bed with regards to sorting and grading (both normal and reverse). The inclination of beds may range from 70 to 80^o near the pipe margins to flat-lying at depth and in the central parts of the pipe. All four lithologies form beds ranging from centimetres to tens of metres.

Abrupt changes in bedding direction are apparent and individual units appear to be both truncated by and in other areas coalesce with neighboring layers. This is especially true near thick deposits of CK.

Warping, block faulting, and load cast features are common effects of differential compaction and sedimentary loading. Further supporting a dominance of sedimentary processes is the well preserved, uncarbonized wood fragments found deep within some of these pipes. Many have been analyzed and indicate deposition at low temperatures of less than 50^{o}C (Nassichuck, 1995). These temperatures do not support a purely volcanic mode of emplacement.

Pipe Formation Model for Some Kimberlites in the Lac de Gras Region

The lithologies and features described here would not have resulted from the processes that form tuffisitic kimberlite in the diatreme facies. Although pipe morphology is well developed, typical diatreme facies lithologies are rarely observed in the shallow portions of these bodies. How then is it possible to get such well developed complex sedimentary features at 300m depth or more in what is essentially a 100-200m diameter tube?

The following emplacement model is proposed.

Initial Kimberlite Eruption

Kimberlitic magma migrating upward from the mantle under high pressure meets competent rocks of the Slave Province. As the highly pressurized kimberlite melt migrated upward through the country rock it took advantage of existing structural weakness, making its way to the surface following networks of existing fractures.

The magma finally breached the earth's surface, violently erupting through a restricted vent and forcefully expelling kimberlite and country rock to create a narrow, steep-sided conduit nearly free of debris and surrounded by a massive crater rim deposit (figure 1).

Similar to non-kimberlitic volcaniclastic accumulations, the crater rim deposits comprise kimberlite ash, lapilli and block tuffs intermixed with country rock fragments. Typical of volcanic vents, larger, denser clasts and grains were preferentially

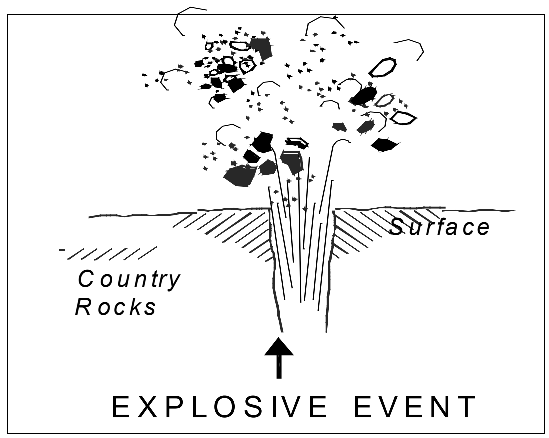

Figure 1: Restricted vent focuses eruption, resulting in expulsion of kimberlite and country rock fragments.

deposited proximal to the edges of the vent while finer, lighter material was deposited stratigraphically higher and further from the vent. Large volumes of very fine ash material may have been winnowed off during the eruptive phase, resulting in a crater rim deposit relatively enriched in larger and denser particles (Fisher et al, 1984).

As the kimberlite and granite fragments were continually cleared from the narrow vent as ejecta, typical diatreme lithologies such as tuffisitic kimberlite and tuffisitic kimberlite breccia were limited to the deepest portions of the pipe. Pyroclastic debris of variable thickness overlies the tuffisitic kimberlite.

This expulsion of kimberlite material from the vent allowed for effective degassing and rapid cooling, resulting in an abundance of well-preserved olivine with little serpentinization.

Infill Sedimentation Process

After kimberlite volcanic activity ceased, the empty vent filled with water to form a crater lake into which eroded crater rim debris was continually deposited. Subaqueous sedimentation occurred by 3 main processes in recurring cycles:

1) Continual seasonal inward wash of debris
2) Catastrophic Mass flow
3) Interflow settling

Continual Seasonal Inward Wash of Debris

With the effects of gravity and seasonal precipitation the unconsolidated crater rim suffered from continual erosion and deposition into the crater lake. These sediments are well sorted, generally fine grained, and were susceptible to re-working during transport to the crater lake (FSK). This material formed extensive well bedded and graded alluvial fan-like deposits.

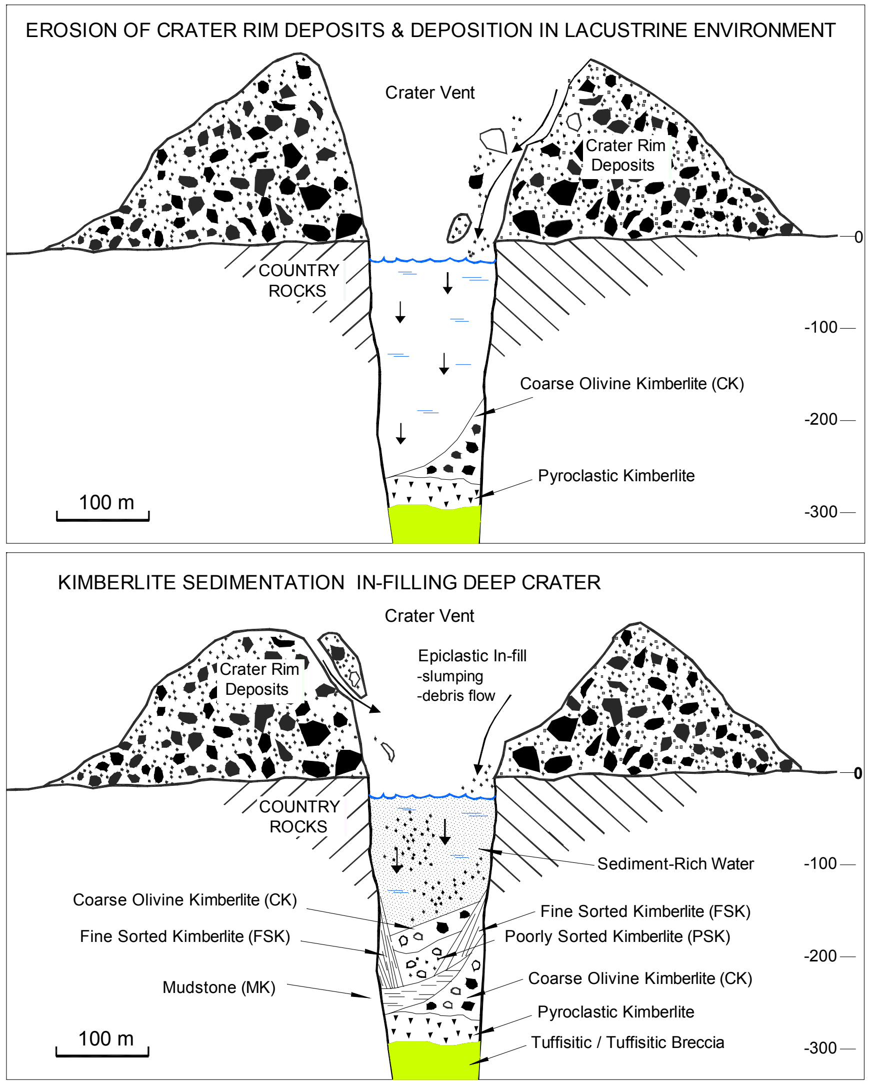

Figure 2: Schematic drawing showing sedimentary infill process resulting from mass flow, interflow settling and inward wash of sediments.

Mass Flow

Continued seasonal erosion of the crater rim material led to removal of fine sediments, unstable slopes and eventual catastrophic mass wasting (figure 2). Massive debris flows slumped into the water-filled vent forming coarse grained clast or grain supported deposits containing a high proportion of coarse olivine and large country rock fragments (CK). These deposits exhibit sub-vertical layering and variable sorting by grain size and density. The coarser and denser material tends to be more abundant near the pipe margins and at the base of mass flow deposits.

Interflow Settling

Each mass flow event was marked by deposition of coarse material followed by an interflow settling period (figure 2). As the mass flow passed into the crater lake (through the dense water medium), the fine material went into suspension. These fine particles eventually settled out as substantial mud deposits (MK) blanketing the debris flows. These penecontemporaneous mudstone deposits formed circular wedges or conical deposits which attained greatest thickness at the toe of the coarse flows. Depending on the amount of time between mass wasting episodes, the mudstone deposits compressed and lithified.

This sedimentation cycle repeated until the pipe was completely in-filled. Well-lithified mudstone beds were preserved and buried by subsequent mass flows. Semi-lithified mudstone deposits were completely or partially destroyed and incorporated as “rip-up” clasts distributed throughout a subsequent mass flow (CK). There is a notable concentration of these clasts at the base of the coarse clastic flow deposits. The soft fragmented mudstone retained its integrity as discrete clasts but deformed due to soft sediment deformation and differential loading. Where abundant, these fissile irregularly shaped 2 mm to 50 mm clasts often coalesced to form thin mudstone stringers with interstitial lenses of olivine grains. Olivine is commonly embedded along the margins of kimberlitic mudstone clasts. During periods with frequent mass flows the debris impacted and mixed with the unconsolidated kimberlite mud forming poorly sorted matrix-supported kimberlite (PSK).

DIAMOND DISTRIBUTION

Predicting diamond size distribution from microdiamond populations within each of the generalized kimberlite lithologies can be problematic due to the depositional nature of the kimberlite. An early understanding of the pipe emplacement will assist in the exploration and interpretation of the diamond distribution data. Clearly, early recognition of the presence of deep crater facies and the controlling factors in pipe formation is crucial in order to plan a drill program that will provide the stratigraphic and microdiamond information necessary to properly evaluate the economic potential of these kimberlites.

In the Lac de Gras deep crater model kimberlites, diamond content is not controlled solely by the original diamond carrying capacity of the intruding kimberlite phases. Diamond content and size distribution is controlled by gravity and particle size deposition within discrete sedimentary beds. Very coarse kimberlite with concentrations of heavy particles will preferentially be enriched in larger diamonds and finer well-sorted kimberlite material concentrated in heavy kimberlite minerals will be enriched in small diamonds while containing few large stones (figure 3).

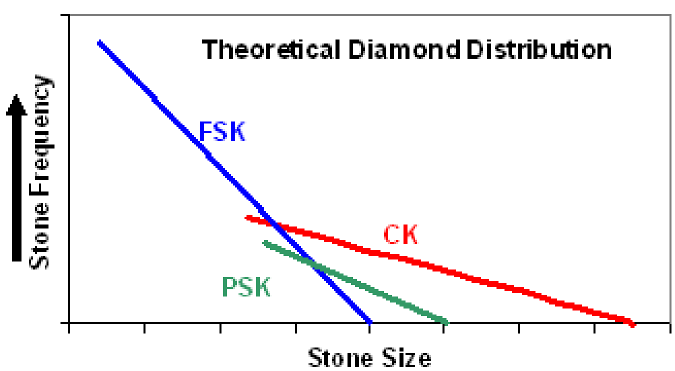

FIGURE 3: Theoretical microdiamond distributions shown for described lithologies. FSK- high stone frequency in the finer fractions and few stones in the coarse fraction. CK- low stone frequency in the fine fraction and presence of coarse fraction stones. PFK- similar to CK, but diluted by matrix mud. Mudstone kimberlite not shown because it is considered barren of recoverable diamond sizes.

DIAMOND DISTRIBUTION IN THE FINE WELL SORTED KIMBERLITE (FSK)

The well sorted fine grained kimberlite is made up of fine grained particles. Microdiamond analysis of samples recovered from a thick unit of the well sorted fine grained kimberlite (FSK) may yield moderate to high microdiamond counts, however since there is a bias towards smaller particles, there is a bias towards smaller stones. Furthermore, if the FSK unit has concentrated fine minerals of lower density, a microdiamond sample may return low counts of small diamonds even within what may be an economic pipe.

Any larger stones originally in the crater rim would likely be deposited in the coarser kimberlite sediments elsewhere in the pipe. The microdiamond data only provides an indication of the diamond content in the FSK, but would provide no information on any other lithology within the pipe. Even a larger sample of this material will yield few large stones. If the mode of emplacement of the kimberlite is not recognized, these poor diamond results could lead to abandonment of exploration on a particular pipe that may be economic due to undetected enriched kimberlite units.

DIAMOND DISTRIBUTION IN THE POORLY SORTED MATRIX SUPPORT KIMBERLITE (PSK)

In the poorly sorted matrix-supported kimberlite one can expect to find a full range of diamond sizes. However, a large portion of matrix (ash) material will cause a dilution effect of the larger particles including diamond (figure 3). To properly evaluate the diamond content of these rocks, a large sample is required. Microdiamond samples as large as 100 to 200 kg may not yield enough diamonds to properly evaluate the kimberlite unit and certainly not enough to evaluate a deep crater kimberlite pipe.

DIAMOND DISTRIBUTION IN THE COARSE GRAIN/CLAST SUPPORTED KIMBERLITE (CK)

The coarse grained kimberlite sediments are generally biased towards larger stones. A small sample of coarse kimberlite (CK) for microdiamond analysis may report low microdiamonds counts, even though it may be enriched in larger stones (figure 3). Due to the overall diamond enrichment, diamond content of this unit can be evaluated fairly easily assuming a large enough sample is processed.

High concentrations of country rock fragments in tuffisitic kimberlite breccia within the diatreme facies can reduce diamond grade due to dilution. In the CK sediment, a concentration of large country rock fragments often indicates an enrichment of larger diamonds as there is concentration by size and density due to gravity. In these rocks, not only is the grade higher, but since there is a bias towards larger stones, there is generally a significant increase in the value per carat.

Near pipe margins there may be a preferential increase in the grade and overall stone value.

Diamond distribution in Kimberlite Mudstone (MK)

The kimberlitic mudstone units may attain great thickness and are considered barren of diamond. These rocks essentially decrease the overall grade and value of a kimberlite pipe.

CONCLUSIONS

There are four generalized kimberlite lithologies common to many Lac de Gras kimberlite pipes. The lithologies are:

1) Fine grained well sorted kimberlite
2) Coarse grained matrix supported kimberlite
3) Coarse grained grain/clast supported kimberlite, and
4) Mudstone/siltstone kimberlite

These rock types are epiclastic in origin and their final emplacement is controlled by sedimentary processes. The emplacement of these kimberlites is related to violent eruptions through a restricted, small diameter vent causing large crater rim deposits to accumulate around a nearly empty well cleared vent. Upon cessation of the eruption, the crater rim erodes and is ultimately deposited into the crater under lacustrine conditions.

A consequence to the reworking of the kimberlite debris and deposition by complex sedimentary processes is the re-distribution of the diamond content. Due to the complex internal stratigraphy and the variability of diamond content in each generalized lithology, it is particularly difficult to assess the diamond content of these kimberlites both for microdiamond analysis and for development of a resource model. During early exploration of a pipe, it is imperative that the sedimentary processes are recognized through systematic geological logging of drill core from the initial drillhole(s) to ensure that enough drilling is completed to allow for a proper assessment of the pipe and to allow for proper interpretation of microdiamond data.

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REFERENCES

Nassichuck,W.W., McIntyre, D.J, 1996. Fossils from diamondiferous kimberlites at Lac de Gras: age and paleogeography: NWT, Canada. Geological Survey of Canada, OF 3228, pp. 43-46.

Fisher, R.V., Schminke, H.U., 1984. Pyroclastics Rocks. Springer-Verlag, Berlin.

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