The Importance of Kimberlite Geology in Diamond Deposit Evaluation : A Case Study from the DO27/DO18 Kimberlite, NWT, Canada

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INTRODUCTION

Diamonds formed during the Proterozoic and Archaean and are in-homogenously distributed in the mantle below Archaean cratons. Kimberlite magmas usually form well within the diamond stability field and physically incorporate seemingly random amounts of diamonds during their ascent through the mantle. The diamond content of a kimberlite magma arriving at the earth's surface is defined by ascent processes. Once a pulse of magma arrives close to the earth's surface, the diamond distribution within the resulting consolidated kimberlite depends on the final emplacement processes. Multiple pulses of kimberlite typically form a single body and each pulse has a different diamond content and emplacement history. Thus, the diamond distribution within single kimberlite bodies can be complex. The understanding of the geology and emplacement history of kimberlite bodies plays a critical role from early exploration through to mineral deposit evaluation, resource determination, deposit economics, mining and resource reconciliation.

KIMBERLITE GEOLOGICAL MODELS

The internal geology of a body is determined using drill cores and/or chips and any exposures available through sampling or trial mining. Three dimensional geological models of pipe geometry and internal variances are constructed using the data collected from logging drill materials or mapping exposures and are based on visual examinations including petrography. Other data such as geophysical parameters, density, clay mineral content, abundances of indicator minerals, microdiamonds and macrodiamonds should also be incorporated into these models. The data available are always spatially limited and an important part of constructing geological models is extrapolating between data points using predictive geology based on the understanding of previously investigated kimberlites. The degree of confidence in any geological model depends on many factors including the spatial distribution and quality of the rocks available for examination. Understanding the drill materials and the development of the geological model is not a trivial task and depends on the experience of person(s) undertaking the work. Importantly, the development of models is an ongoing iterative process which must take into account new materials or data as they become available.

The geological models attempt to define the internal geology in terms of geological units, their geometries, volumes, densities, diamond distribution, grade and continuity or variation of grade. Other geotechnical and metallurgical characteristics are also essential, particularly in more advanced projects. Simplifications, errors or omissions of important characteristics of a deposit can, and do, produce prospects that are difficult to explore and evaluate and can lead to misleading feasibility studies, shortfalls (or more rarely excesses) in production, incorrect mining methods and a generally mining and economic failures.

Diamond distributions reflect the mode of emplacement and nature of each kimberlite unit present in a deposit. Diamond grade (carats per tonne), stone density (stones per tonne), diamond size distribution and diamond value usually vary between different units but also can all vary within apparently single units. All of these factors contribute to the overall critical figure, the ore value ($ per tonne). It cannot be assumed that any of these criteria remain constant (or random) within, or between, kimberlite units. Diamonds are merely distributed by the kimberlite, not formed within kimberlite. Diamonds, in part because if their high specific gravity, are distributed differently by specific primary emplacement processes, and by later secondary modifying processes during re-working or erosion.

Individual geological models for specific bodies such as those of Clement (1982) can be grouped together to produce more generalised models. Pre-1990 detailed studies focused on the southern African mines. The generalised kimberlite model based on these deep steep-sided pipes has three distinct zones: (i) a root zone of hypabyssal kimberlite, (ii) a “diatreme” zone infilled with tuffisitic kimberlite and (iii) an upper crater zone of pyroclastic and reworked near surface deposits (Hawthorne 1975; Clement and Skinner 1985). The diamond distribution varies in accordance with differences in emplacement processes in the three contrasting zones (Clement 1982). Since 1990 and the discovery of hundreds of kimberlites across Canada, new generalised geological models were required to describe the bodies that are extremely different to those of southern Africa (Field and Scott Smith 1999). The exploration and evaluation of one of these newly discovered kimberlite bodies serves to illustrate the importance of kimberlite geology in resource development and how a poorly constrained geological model can lead to erroneous project decisions costing tens of millions of dollars.

DO27/DO18 CASE HISTORY

The DO27 and DO18 kimberlite complex was found in 1993 during the diamond rush in Canada’s NWT that occurred after the discovery of the first kimberlite at Point Lake in 1992. The latter discovery led to the Ekati^{tm} Mine that opened in 1998. The DO27/DO18 complex occurs 57 km from the Ekati^{tm} diamond mine and thus forms part of the large Lac de Gras kimberlite province. The claims containing the DO27/DO18 kimberlite complex was initially staked by DHK Resources (a consortium of Dentonia Resources, Horseshoe Gold and Kettle River Resources). They optioned the property to Kennecott Canada Exploration Inc. who discovered the kimberlite complex as the result of drilling a magnetic high with coincident resistivity low anomalies. Gravity surveying indicated a larger body with DO27 in the south having continuity to the DO18 to the north. This kimberlite complex was initially known as Tli Kwi Cho. The complex was envisioned as having a surface plan view area of ~24 hectares, approximately 1,200 meters in NS length and with an average width of approximately 200 meters. The kimberlite occurs within the granitic rocks of the Archean Slave Province. An accurate age of emplacement has not been determined. Evaluation of this body has continued since its discovery and a series of geological models have been developed. The development and consequences of these geological models are considered further below.

Model 1 - 1993/4: The initial model for DO27/DO18, attempted to follow the classical southern African model, envisioning a single large body and drilling and exploration proceeded based on this assumption. The early operators struggled with an interpretation. Drill holes passing in and out of kimberlite and granite indicated a complex body where the rock types did not fit the geology. Also this apparently 24 hectare body was larger than most of those in the area, now forming the Ekati^{tm} and Diavik^{tm} Diamond Mines..

Model 2 – 1994: DO27 and DO18 were recognised as distinct, separate kimberlite pipes. Drilling showed that some kimberlite occurs between the two main pipes. Of the two bodies, DO27 appeared to be more interesting based on the results of microdiamond analyses and thus was focus of subsequent work. Three megascopically distinct kimberlite units were recognised within DO27: (i) green “pyroclastic” kimberlite, (ii) dark “diatreme” kimberlite with associated extensive granite breccia and (iii) black fragmental kimberlite. The latter rock type is similar to kimberlites found elsewhere in the area and contains abundant Cretaceous shale indicating that the kimberlite was emplaced before 74 Ma. and that the area was overlain by shale at the time of emplacement (Doyle et al. 1999). The overall model envisaged was of a large steep sided pipe in-filled with granite-rich diatreme-facies kimberlite comparable to the southern Africa kimberlite model. At the same time there were also claims that many of the other kimberlites in the Lac de Gras area were also diatreme-facies. The green pyroclastic and black fragmental units were considered to be crater-facies material. A postulated “reserve” was calculated by Kennecott Exploration Inc., containing 15 to 22 million tonnes of “diatreme” kimberlite, 23 to 25 million tonnes of pyroclastic kimberlite, and 3 to 6 million tonnes of included “granitic raft” in two separate pipes.

Microdiamond results of samples of drill core were considered sufficiently encouraging to warrant the development of a decline which was driven into the outer portion of the pipe and from which a bulk sample of 4,261 tonnes of kimberlite was processed. The operators apparently believed that this limited sampling was representative of the two largely homogenous main rock types. In August of 1994 the results from this sample were released: 3,000 tonnes of pyroclastic kimberlite returned an average grade of 0.36 cpt (at $21/carat) and the “diatreme” material ran only 0.013 cpt at a somewhat higher diamond valuation. These results, in which the bulk sampling of the DO27 pipe did not produce the anticipated high grades, led to a catastrophic Canadian junior stock market crash and abandonment of the project.

Model 3 – 1995: The original JV partners, especially George Stewart of Kettle River, believed that the previous work, especially the macrodiamond sampling of possibly peripheral kimberlite, was insufficient. The construction by Kettle River of a physical geological model indicated that the geological interpretation was inadequate. The re-examination of the geology based on the original drill cores confirmed the three main broad rock types of Model 2 but the interpretation of them differed (Doyle et al. 1999). Rock type (iii) the black fragmental kimberlite, was interpreted as a low interest wood-bearing, shale-rich free olivine- and juvenile lapilli-bearing resedimented kimberlite similar to rocks occurring elsewhere at Lac de Gras. Microdiamond results suggested that this unit had low macrodiamond contents. Rock type (ii) the so-called “diatreme” kimberlite was re-interpreted as an intrusive hypabyssal sill complex formed by multiple magma pulses with variable but low xenolith contents. The so-called granite rafts and breccias represent in situ country rock sometimes with increased fragmentation probably caused by the intrusive sheet emplacement. The consequences of this re-interpretation include (1) a dramatic reduction of the potential resources volumes, (2) a lack of potential extrapolation above and below the sill complex between 70-160m from the present surface and (3) very different mining model. If mineralised, both rock types (ii) and (iii) would have complex diamond distributions. In contrast, the so-called pyroclastic kimberlite was re-classified as a relatively uniform, xenolith-poor, juvenile lapilli-bearing, free olivine-rich, fines depleted pyroclastic kimberlite. This rock type in-fills a relatively large step-sided bowl-shaped crater with a surface area of 9ha. The re-assessment of the crater shape significantly changed the resource volume. The other main part of the complex, DO18, is in-filled by very different kimberlite, a xenolith- and xenocryst-rich juvenile lapilli-bearing olivine volcaniclastic kimberlite. Kimberlite breccias and micro-breccias are common. The detailed nature of the four main rock types at DO27-DO18 strongly suggested that the pyroclastic kimberlite has the highest economic potential and the highest volume ore reserves. The early bulk sampling was undertaken in the marginal areas of the large pyroclastic kimberlite. Some large scale features such as lateral fining were thought to be present and were possibly also reflected in earlier microdiamond results. The general area of sampling does display differences to the overall relatively uniform main pyroclastic kimberlite, perhaps even representing a different crater. Thus, the macrodiamond sampling did not intersect the main pyroclastic crater deposits in the DO-27 pipe and the sample treated was not representative. The results clearly indicated that further sampling of the main areas of this rock type was warranted and that the variation in macrodiamond grades within the main parts of this unit may be limited.

Model 4 – 2006: In 2004 Peregrine Diamonds Ltd. acquired an interest in the project and in 2005 began work on the project. Subsequent exploration modelling, core drilling and bulk sampling based on updated models has returned significantly higher diamond grades (central zone yielded sample grades of 0.98 cpt) as well as an increased understanding of the nature and emplacement history of the pyroclastic kimberlite. These results confirm the interpretation of the pyroclastic kimberlite of Model 3 and an enhanced geological model is being constructed based upon current drilling (Harder et al., this volume).

The DO27 body is asymmetrical in shape and potentially comprises separate vents, the main vent and a smaller, earlier vent in the northeastern part of the body (Doyle et al. 1999). The DO-27 pipe is dominated by pyroclastic kimberlite which appears to be largely homogeneous with respect to juvenile constituents, but displays differences in alteration of xenoliths, olivine and matrix components in various parts of the pipe. The northeastern zone is complex and comprises several units of pyroclastic, volcaniclastic, and magmatic kimberlite that can be correlated between drill holes. Pyroclastic kimberlite is volumetrically most significant in the northeast zone, and may correlate with pyroclastic kimberlite from the main vent. Beneath this pyroclastic kimberlite is a complex volcaniclastic kimberlite zone. This volcaniclastic zone likely represents the products of early eruptions and crater rim slumping. Much of the northeastern lobe is underlain by magmatic kimberlite breccias, which likely belong to the HK sill complex described by Doyle et al. (1999). The 1994 DO27 bulk sample contained material only from the complex northeastern zone, and was dominated by magmatic kimberlite, possible volcaniclastic kimberlite, and some pyroclastic kimberlite. Geological observations from core drilling and recent micro-diamond results further substantiate that the upper and lower volcaniclastic units of the north-eastern lobe of DO27 are geologically distinct from the pyroclastic unit of the main vent. Much of the 1994 bulk sample of DO27 appears to have been from a restricted horizon of the lower volcaniclastic unit of the north-eastern lobe of the kimberlite and from the volumetrically insignificant hypabyssal sheets, and therefore is not representative of the main part of the pipe. The 2005 bulk sample covers part of the main PK unit, and the 2006 bulk sample (treatment in progress) covers much of the main PK and possibly portions of the north-eastern lobe.

CONCLUSIONS

The Tli Kwi Cho case history shows the importance of the kimberlite geological model in the resource evaluation. Even after extensive drilling (1993-4: 56 holes), model dependent interpretations of the geology can give vastly different ore resource estimates (tonnage). Early interpretations (Models 1 & 2) were assisted by the unusually distinctive rock types. Re-interpretations of the rock types significantly modified the resource estimates. Estimates based on a carrot-shaped diatreme southern African-style pipe containing large granite xenoliths results in more optimistic ore resource estimates than those based on the newer models (Models 3, 4) where the kimberlite “diatreme” is re-interpreted as a volumetrically insignificant buried sill complex. Although not an exploration target at this time, any diamond grades obtained for the xenolith-poor hypabyssal kimberlite from this area might require reduction to provide more realistic mining grade estimates reflecting dilution by country rock.

More importantly, with a better understanding of the geology, the “target” has changed from the low grade, hypabyssal material that was originally interpreted as the main “diatreme” infill, to the pyroclastic material that fills the main crater. The pyroclastic kimberlite contains significant quantities of diamonds and has been drilled to a depth of 450m beneath surface, suggesting that a significant volume of this material is present, much more than had been interpreted in early models.

The DO27/DO18 complex is clearly different from both previously understood southern African kimberlites and most of the other Lac de Gras pipes. It contains no diatreme facies kimberlite, as found in the the southern African pipes. DO27/DO18 differs from other bodies in the Lac de Gras province because it by contains significant hypabyssal kimberlite in a sill complex and because pyroclastic kimberlite is more common than shale-rich resedimented kimberlite.

The Tli Kwi Cho DO18/DO27 kimberlite case history shows that geology is a critical part of exploration and evaluation, and how incorrect or misleading interpretations and postulated models can lead to project success or failure. The details of the geology gathered through careful, systematic and meaningful investigations carried out by experienced geological personnel, and the continuity of a geological team are key to wealth creation in mining.

REFERENCES

Clement C.R., 1982. A comparative geological study of some major kimberlite pipes in the northern Cape and Orange Free State. Unpublished PhD Thesis, University of Cape Town, South Africa.

Clement C.R. and Skinner E.M.W., 1985. A textural-genetic classification of kimberlite. Transactions Geological Society of South Africa, V.88, pp. 403-409.

Doyle B.J., Kivi K. and Scott Smith B.H., 1999. The Tli Kwi Cho (DO27 and DO18) diamondiferous kimberlite complex, Northwest Territories, Canada. Proceedings of the VIIth International Kimberlite Conference, Volume 1. Red Roof Design, South Africa. pp. 194-204.

Field M. and Scott Smith B.H., 1999. Contrasting geology and near-surface emplacement of kimberlites in southern Africa and Canada. Proceedings of the VIIth International Kimberlite Conference, Volume 1. Red Roof Design, South Africa. pp. 214-237.

Harder M, Hetman C, Scott Smith BH and Pell J, this volume. Geology model of the DO27 pipe – a pyroclastic kimberlite in the Lac de Gras Province.

Hawthorne JB, 1975. Model of a kimberlite pipe. Physics and Chemistry of the Earth, V. 9. pp. 1-15.

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