The evolution of geological models for the DO-27 kimberlite, NWT, Canada: implications for evaluation.

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Introduction
The DO-27 kimberlite is located within the Lac de Gras province on the Slave Craton, Northwest Territories (NWT), Canada, that includes the EKATI™ and Diavik™ diamond mines (see Figure 1, Harder et al., 2008). The Lac de Gras kimberlites were emplaced into predominantly Archean granitoids of the Slave Province and an overlying veneer of late Cretaceous to Eocene mudstones (Doyle et al., 1999). The DO-27 body is part of what was historically known as the Tli Kwi Cho complex, which was discovered in 1992, and has undergone a long history of exploration and evaluation by a number of operators. Evaluation of the kimberlite was conducted based on contrasting geological interpretations, which lead to significantly different estimations of the kimberlite area, volume and grade of kimberlite present. This contribution discusses the different geological models at various stages in the project history, the impact this had on the project, and the implications for evaluating other kimberlites.

Model 1: Discovery, 1992
The initial Model 1 after the discovery of the DO-27 body (red outline, Fig. 1) was a large geophysical anomaly after which the kimberlite was named, with a subordinate anomaly to the north named DO-18 (Fig. 1, red outline; Model 1, Table 1; Coopersmith et al., 2006; Doyle et al., 1999). The separate geophysical anomalies were approximately circular in shape, with the DO-27 anomaly appearing to have two lobes (Doyle et al., 1999). These anomalies were extensively evaluated over the following year.

Model 2: Ground Geophysics, 1993
Model 2, which was based on ground magnetic and gravity surveys, combined the two anomalies of Model 1. The DO27/DO18 complex was thought to represent a much larger (24 ha) single pipe with an irregular surface outline (Fig. 1, dotted outline; Table 1; Coopersmith et al., 2006; Doyle et al., 1999). The surface area suggested by this model was comparable in size to the large typical southern African-style kimberlites, but was inconsistent with other much smaller pipes discovered in the Lac de Gras region at the same time. During 1993, a total of forty-four drill cores were collected from the DO-27 anomaly and thirteen from the DO-18 anomaly (Doyle et al., 1999). As the drill holes were completed, it rapidly became apparent that there were at least two separate bodies which were named DO-18 and DO-27 after their respective geophysical anomalies. The extensive drillcores allowed a more detailed interpretation of the geology, particularly of the southern DO27 anomaly which led to Model 3, the first detailed geological model.

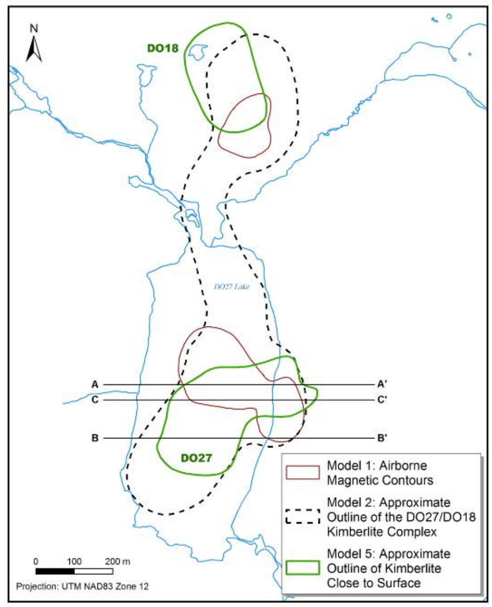

Fig. 1 Model 1 (red outline) and Model 2 (black dotted outline) for the plan view outlines of the DO27/DO18 complex (after Doyle et al., 1999). The green lines are the current modeled outlines projected to surface for the DO-18 (Harder et al., this volume) and DO-27 pipes (Model 5, Fig. 5).

Model 3: Early Geology, 1993-1994
Model 3 was considered to be a large, southern African-style kimberlite (Model 3, Table 1; Fig. 2) comprising three contrasting rock types (Doyle et al., 1999): (i) a dominant pipe-infill of granite-rich 'diatreme-facies' kimberlite which includes large granite 'rafts' (Fig. 2), (ii) lesser 'crater-facies' pyroclastic kimberlite (PK) and (iii) mud-rich resedimented volcaniclastic kimberlite (RVK). In assuming that the DO-27 body was a large southern African-style kimberlite, considerable amounts of kimberlite were assumed in un-drilled areas of the pipe (Table 1; Fig. 2). In the fevered atmosphere of early kimberlite discoveries in the NWT, the evaluation of the DO-27 kimberlite was rushed to the bulk sampling stage via an underground ramp, which was completed

in 1994. The ramp was intended to test what was considered to be the volumetrically dominant rock type at DO-27, the ‘diatreme-facies’ kimberlite, with an extension into the poorly constrained and undifferentiated ‘crater-facies’ kimberlite (PK and RVK). Due to underground development issues including water problems and bad ground, the ramp was not able to extend as far as planned, and only sampled kimberlite from a restricted, marginal area of the pipe. The macrodiamond sample grades ranged from 1.3 to 36 carats per hundred tonnes (cpht), with the lower grades obtained from the ‘diatreme-facies’ material (Table 2). These results did not meet the expectations of the original operators who decided not to proceed with further evaluation of the pipe.

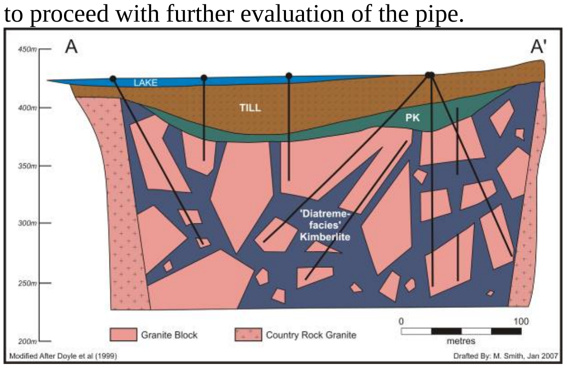

Fig. 2 Schematic cross section illustration of Model 3 for DO-27 which proposed a large southern African-style pipe infilled with ‘diatreme-facies’ kimberlite containing abundant granite ‘rafts’. See Fig. 1 for location. After Coopersmith et al. (2006) and Doyle et al. (1999).

Model 4: DO-27 Re-interpreted, 1995

Some stakeholders in the project maintained that the 1994 bulk sample was not representative of the pipe and they acquired a re-examination of existing drill cores in 1995, shown here as Model 4 (Doyle et al., 1999). Although this new study generally agreed with the original rock type sub-divisions, the interpretation of the rock types, the geological model and the emplacement mechanisms were very different. The ‘diatreme-facies’ kimberlite (Fig. 2) was re-interpreted as a volumetrically minor, pre-pipe, shallow-inclined intrusive sheet complex of hypabyssal kimberlite (HK) within fragmented, in situ country rock granite (Fig. 3). The ‘crater-facies’ PK was confirmed as pyroclastic in origin, but was identified as the volumetrically dominant pipe infill (Fig. 4). The mud-rich RVK was also confirmed as volcaniclastic kimberlite (VK), and was identified as a volumetrically minor unit present to the north and north-east of the main PK-filled pipe. The DO-27 kimberlite was interpreted to comprise two separate vents, a smaller north-east vent and a larger, younger vent to the south-west. The younger vent represented the main DO-27 crater and contained the majority of the PK observed at DO-27 (Fig. 4). This interpretation assumed little kimberlite in un-drilled areas of the body, and dramatically reduced the proposed volume of kimberlite available (Model 4, Table 1). Model 4 also confirmed that the 1994 bulk sample was not representative of the volumetrically dominant rock type, PK, from the main crater area.

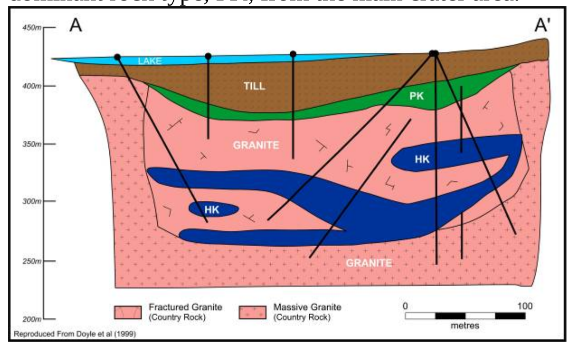

Fig. 3 Model 4 illustrated for the same cross section as Fig. 2. This model proposed low-volume intrusive (HK) sheets separated by fragmented, in situ country rock granite (after Doyle et al., 1999). See Fig. 1 for location.

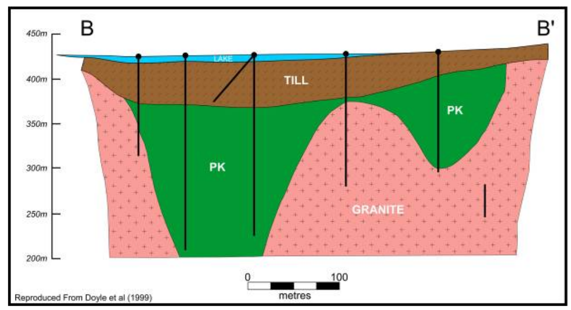

Fig. 4 Model 4 identified the volumetrically dominant kimberlite domain at DO-27 to be the PK, which was interpreted to have been emplaced through two separate vents (after Doyle et al., 1999). See Fig. 1 for location.

Model 5: DO-27 Advanced Evaluation, 2005-2008

Despite significant revisions to the geological model of DO-27, no significant further work was undertaken until 2005, when Peregrine Diamonds and joint-venture partners commenced a re-evaluation of the body including bulk testing and extensive core drilling focused on the PK. A bulk sample program completed during 2005-2007 indicated that the PK has an average sample grade of approximately 89 carats per hundred tonnes (Table 2). Sixty additional core holes delineated the kimberlite indicating a surface area of the PK of approximately 8 ha and a volume, to a depth of 460 m, of approximately 30 million tonnes of VK, over 85% of which is PK (KIMB-1; Fig. 5; Table 1). In contrast to Model 4, DO-27 is now interpreted to have formed by multiple eruptions from one large vent within a single, previously excavated pipe (Fig. 5). This detailed investigation confirmed that the previous suggestion that the PK was deposited by primary processes and is dominated by one overall phase of kimberlite, which is important for the extrapolation of bulk sample results. The more complex VK present in the northeastern part of the body is also observed locally at the pipe margins throughout the rest of the body, and is considered to be a remnant of early pipe infill cut by the later PK-forming eruption (KIMB-3, KIMB-P; Fig. 5). This work supported the interpretation of the coherent/hypabyssal kimberlite (HK) at DO-27 (KIMB-2, Fig. 5) as primarily pre-pipe sills, but also identified minor post-eruption intrusions along pipe contacts and locally some possible late-stage intrusions into pipe-infill.

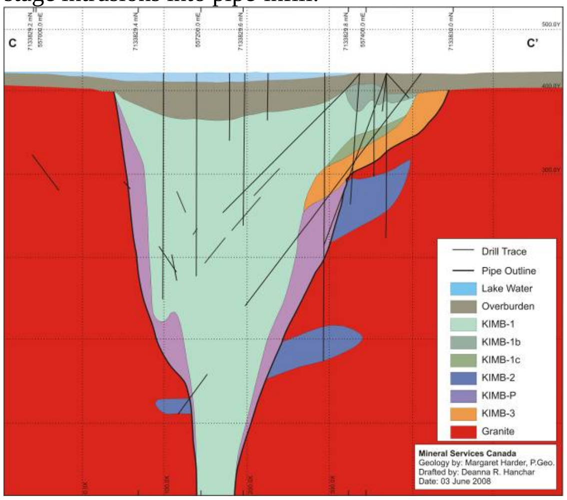

Fig. 5 Model 5 (current model) consists of a single pipe dominated by PK (KIMB-1, KIMB-1b, KIMB-1c), with lesser volumes of VK/RVK preserved along the pipe margins (KIMB-3, KIMB-P). Intrusive coherent sheets (KIMB-2) are common to the north/north-east of the main pipe. See Fig. 1 for location.

Table 1: Summary of geological models for DO-27 including kimberlite area (hectares) or volume (tonnes) estimated according to each model (Fig. 1).

Model	Summary	Year	Tonnes
1	Circular body: geophysics	1992-1993	n/a
2	DO27/DO18 complex: 24 ha	1993	n/a
3	Two bodies: diatreme model	1993-1994	50 million
4	Two bodies: HK sheet model	1995	25 million
5	Current model	2005-2008	*30 million

*Estimate based on 3D wireframe model to a depth of 460 m, and including all VK in the DO-27 crater; this does not constitute a resource estimate.

Table 2: Summary of reported kimberlite sampled (tonnes), diamonds recovered (carats) and grade (carats per hundred tonnes, CPHT) collected from the DO-27 kimberlite (Coopersmith, 2005; www.pdiam.com).

Year	Tonnes	Carats	CPHT	Geological Domain
1994	1157	16	1.3	'Diatreme' (HK)
1994	3003	1079	36	PK (NE lobe)
2005	151	136	90	PK
2006	548	508	88	PK
2007	2520	1724	89*	PK

*Grade reported for the PK domain only, not including other low grade material treated.

Discussion

The evolution of geological models for the DO-27 kimberlite as summarised in Tables 1 and 2 highlights the critical importance of robust geological models for accurate economic assessment of kimberlite pipes. Model 2 highlights the importance of adequate drill coverage in correctly determining the number of bodies present and their size and shape. Many kimberlites occur in clusters, and numerous drill holes are commonly required to provide sufficient geological data to construct an external geological model. Model 3 illustrates that reliable internal geological models are essential in the accurate assessment of kimberlites. By rushing the evaluation process without confirming the geological interpretation, the DO-27 project was negatively impacted, which in turn had serious implications for the Canadian junior stock market (Coopersmith et al., 2006). The significant differences between Models 3 and 4 illustrate that while reliance on broad-scale summary geological models may be very useful as an exploration tool, these models must be applied with caution to new discoveries. The improved understanding of the geology of the DO-27 kimberlite, as shown in Models 4 and 5, resulted in identification of the volumetrically dominant kimberlite domain and changed the predicted economic viability of the DO-27 kimberlite.

Conclusion

The estimated grade of the DO-27 kimberlite based on Model 3 (1993-1994) was 1-36 cpht, which resulted in significantly decreased interest in the project. A revised geological model (Model 4, 1995) lead to a re-evaluation of the kimberlite resulting in much improved estimated diamond grades of the volumetrically dominant kimberlite phase to approximately 90 cpht (Model 5, 2005-2008, PK). Robust geological models, confirmed by numerous drill holes and interpreted in detail by an experienced geologist, are critical to accurate interpretations and ultimately the success of any kimberlite project.

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