CANADIAN KIMBERLITES:
GEOLOGICAL CHARACTERISTICS RELEVANT TO EMPLACEMENT

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INTRODUCTION

Prior to 1984 only ~60 kimberlites were known in Canada. The number had increased to >100 by 1991 and is currently ~800. Many have economic potential which has resulted in a wealth of new data derived from hundreds of drill cores as well as sampling and mining exposures. These data are relevant to kimberlite emplacement. Three types of pipes with contrasting PK, RVK and HK+TK infills (Fig. 1) were proposed by Field and Scott Smith (1999). Those conclusions, based on limited preliminary information, are supported by subsequent data (Figs. 2-5, references therein). Skinner and Marsh (2004) recognise similar distinct kimberlite pipe classes in other parts of the world.

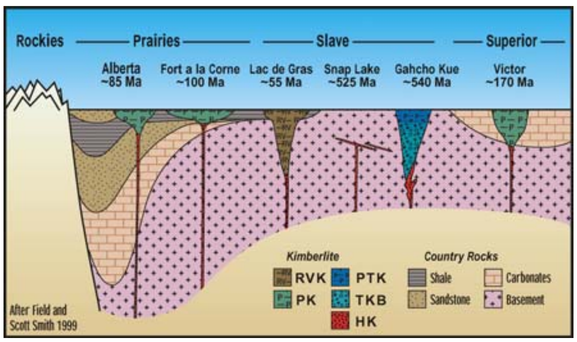

Figure 1 Schematic section across Canada summarising pipe shapes, pipe infills and geological setting reconstructed to the time of emplacement (after Field and Scott Smith 1999).

RVK = resedimented volcaniclastic kimberlite
PK = pyroclastic kimberlite
HK = hypabyssal kimberlite
TKB = tuffisitic kimberlite breccia
PTK = pyroclastic equivalent of TK

Recent data further support the recognition of the three types of kimberlite pipes in Canada and their empirical relationship to the country rock. The Buffalo Hills and Birch Mountains bodies (discovered in 1997 and 1998) are comparable to the other kimberlites in the Prairies. Some kimberlites in the Northern Slave such as Knife Lake, Nunavut (discovered in 2000) contain similar PK and have similarities to Victor being emplaced into Paleozoic sediments. Two new fields of HK-TK-bearing pipes and closely related HK sheets emplaced into only basement granitoids have been found at Renard, Quebec and Aviat, Nunavut (discovered in 2001 and 2002) and are remarkably similar to Gahcho Kué, NWT. Hetman (this volume) adds another new field (Qilalugaq in Nunavut).

Kimberlites have erupted across Canada for over 1000 Ma. and across 5000kms into diverse geological settings within at least two Archaean and three partly reworked cratons. The nature of most of the kimberlite magmas appears to be similar to those in the rest of the world. Thus, the diverse kimberlite geology found in Canada does not obviously reflect differences in magma composition. Typical magmas are composed of ~25% olivine macrocrysts (mantle-derived xenocrysts <15mm), ~25% olivine phenocrysts (<0.5mm) and 50% liquid. In HKs the liquid forms a well crystallised fine grained groundmass (<0.2-0.5mm) with a restricted textural range. The presence of primary phlogopite, serpentine and carbonate shows that the magmas are volatile-rich (H_2O and CO_2).

HK occurs in different parts of Canada as multiple thin (<1-3m wide), steep and shallow dipping, discontinuous tabular bodies. Some are composite, contain abundant volatiles and have diverse textures ranging from aphanitic to macrocrystic, uniform to segregationary to incipient globular segregationary. This textural diversity does not typically occur in HKs in pipe-like bodies (e.g. Gahcho Kue).

Individual kimberlite fields result from magmatism lasting ~10-30 Ma.. Most eruptive centres seem to have formed by multiple pulses of magma in <1-2 Ma.. Although each volcanic centre is unique and commonly complex reflecting variations in the nature of the eruptions and local conditions, each kimberlite field is dominated by one of the three types of kimberlite pipe (Fig. 1) which are shown in more detail in Fig. 2 (in the order they were discovered (A) 1988, (B) 1991 and (C) 1995). Each type of pipe displays contrasting characteristics.

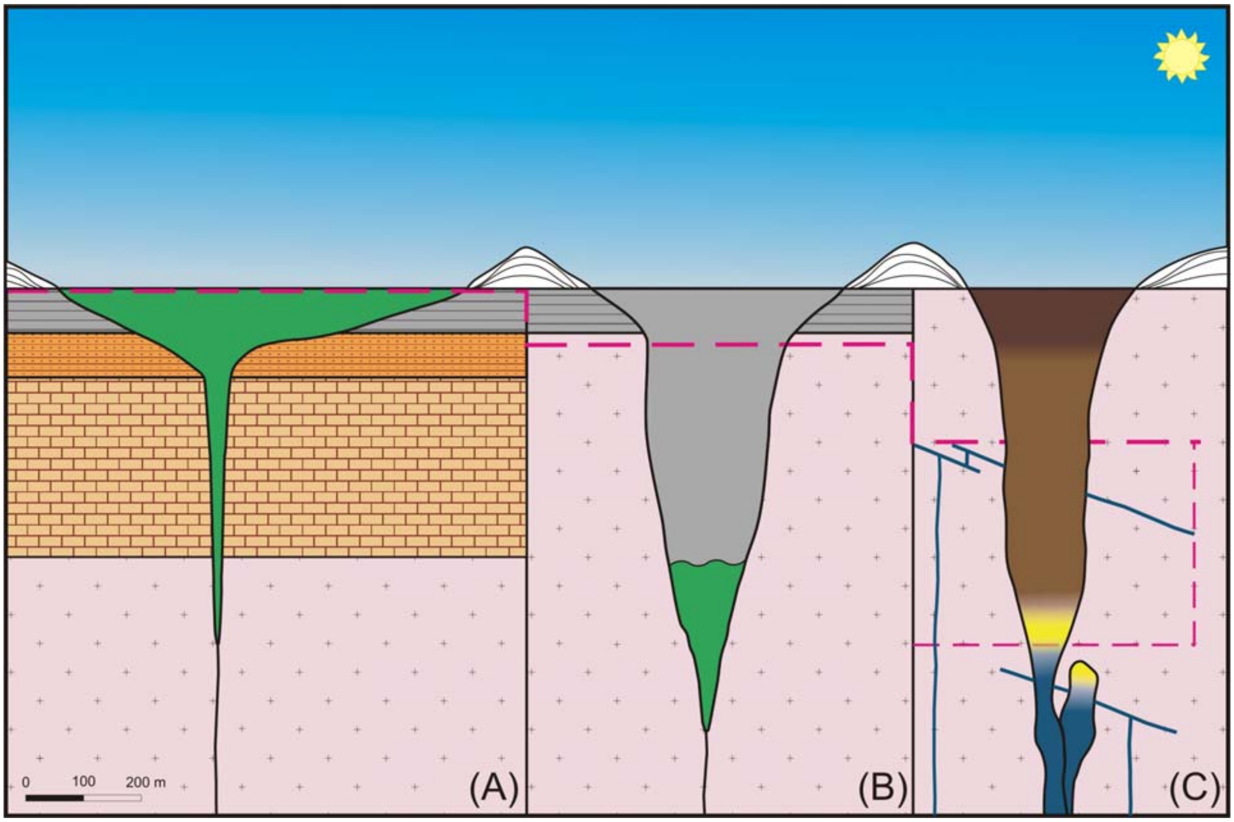

Figure 2 Simplified schematic geology of three contrasting types of kimberlite pipes reconstructed to the time of emplacement (as shown in Fig. 1 and in the order of discovery).
Pink dashed line = present surface. Country rock: grey = shale, orange = siltstone, cream = carbonates, pink = basement. **(A)** The Prairie kimberlites are represented by the medium-sized Fort à la Corne body 169 (Berryman et al. 2004). The dominant infill is PK (green). No TK or HK has been found. In other areas similar PK infills steeper sided bodies (Fig. 1; Webb et al. 2004). **(B)** The Lac de Gras kimberlites are represented by the medium-sized pipe Koala (Nowicki et al. 2004). The dominant infill is shale-rich RVK (grey) and lesser PK (green). Coherent HK-like rocks infill a few pipes (not shown here). **(C)** TK-bearing pipes are represented by the Gahcho Kué composite model (Hetman et al. 2004). The irregular root zone of HK (blue) occurs below a simpler shaped pipe infilled with TKB (brown). There is a textural transition between the HK and TK (yellow). Any pyroclastic material which occurred near surface at the time of emplacement would resemble bedded TKB (dark brown) and, importantly, not PK (green). Relatively common HK sheets (blue lines) occur in the vicinity of all TK-bearing pipes but are absent to rare in the area of the other types of pipe (A) and (B).

CONTRASTING CHARACTERISTICS

The nature of the contrasting infills of the three pipe types (Fig. 2) is depicted in more detail in Figs. 3-5. Pipe type (C) is distinctly different given that it is the only type to contain TK comparable to many pipes in southern Africa. Contrasting Fig. 5 with Figs. 3 and 4 shows that other features exclusive to pipe type (C) are (i) the variation of kimberlite textures with pipe zones, (ii) the presence of a textural gradation between the HK and TK, (iii) the presence of juvenile pelletal lapilli (versus pyroclastic juvenile lapilli shown in Figs. 3 and 4) and microlitic textures, (iv) olivine abundances that do not exceed 30%, (v) the lack of bedding, sorting, loss of fines and carbonate in the TK, (vi) the consistent association with country rock xenoliths of a wide range of sizes (0.5cm-5m) as TKB (B= >15% xenoliths) to TKBB and TKBBB (>50 and 75%, respectively) as well as fractured and pulverized country rock, and (vi) the occurrence of closely related sheets. The infills of pipes (A) and (B) (Figs. 3 and 4) are more comparable to common rock types such as basalts but they do display different characteristics such as the fluidal shapes of the juvenile lapilli, abundant discrete olivines and olivine-dominated PK (up to 80% olivine), mega-graded beds and common serpentine and carbonate as inter-clast cement. Pipe type (B) differs in that there is little evidence for composite pipes or multiple phases of primary infill. These pipes remained empty or some time after formation.

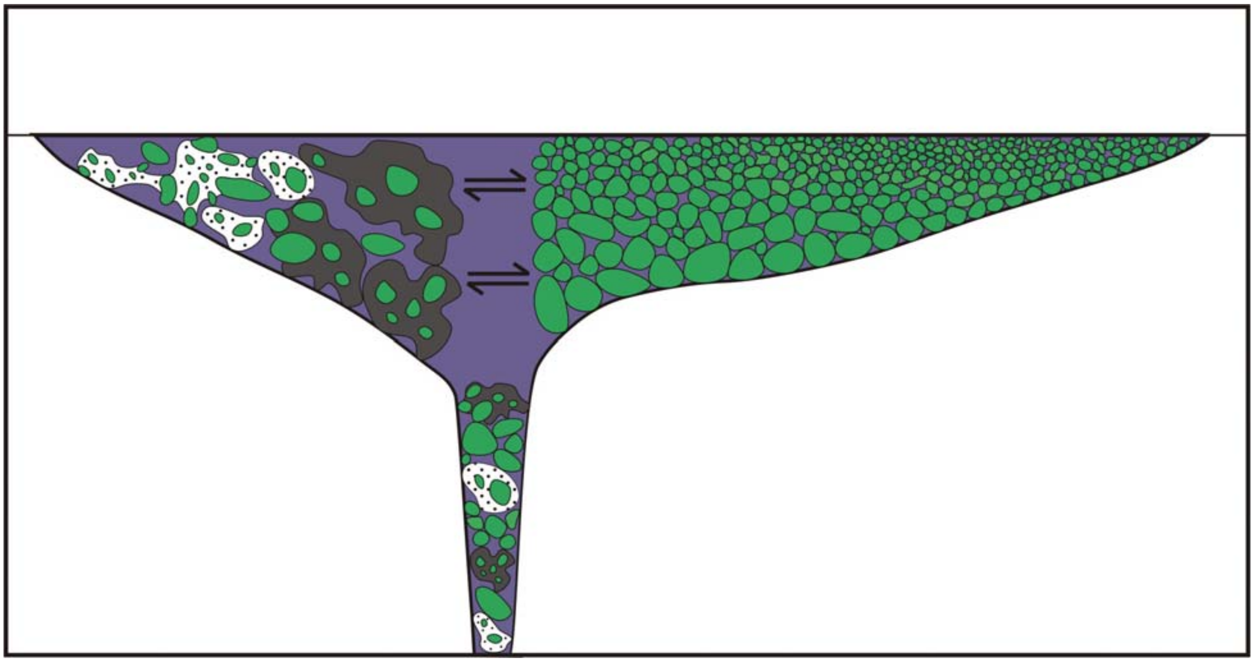

Figure 3 Schematic representation of the dominant pipe infill of the Prairies kimberlites (Scott Smith et al. 1998, Berryman et al. 2004, Webb et al. 2004, unpublished information). Pipe shape from Fig. 2(A). The two main constituents of the PK infill are pyroclastic juvenile lapilli and discrete olivine grains. The juvenile lapilli are composed of olivine (green) plus quenched melt and have fluidal, sometimes, amoeboid shapes (left hand side). The quenched melt is represented by serpentine which is typically isotropic (dark grey) and/or cryptocrystalline carbonate (stippled white). The nature and distribution of olivine within the juvenile lapilli resembles that of HK. The discrete grains of olivine resemble those within the juvenile lapilli and are commonly fresh. Fine constituents (<0.5mm) representing both small olivine grains and the melt, presumably ash, are typically lacking. The rocks have clast supported textures. The interclast matrix is composed of serpentine and less common carbonate (purple background). The low proportion of xenoliths is not shown here. The xenoliths derive from the country rocks shown in Fig. 2 and, in decreasing order of abundance, include carbonates (<15cm), basement (<10cm), shale (<1m) and rare siltstone (<5m). The kimberlites can be broadly sub-divided into three groups composed of (i) predominantly juvenile lapilli (left hand side), (ii) mainly discrete olivine grains (right hand side) and (iii) mixed juvenile lapilli and discrete olivines either within the same phase of kimberlite or in different phases of kimberlite in the same body (as indicated by the arrows and as shown in the feeder vent). Many rocks are bedded with normal grading being common. Most rocks have been sorted. The bedding varies from very thin to rare mega-graded beds (depicted respectively on right hand side if the olivine grains are the actual size or if the crater is the actual size). Multiple phases of PK are present but not shown here.

EMPLACEMENT PROCESSES

The main questions are (1) what processes formed the pipes, and (2) when and how were they infilled? Canadian kimberlite geology provides evidence which constrains emplacement processes. The volatile-rich nature of the erupting magmas must have a significant role. The substantiated correlation of pipe type with country rock geology could indicate variable constraints on volatile concentration and exsolution. The lack of xenoliths of the adjacent country rocks in pipe types (A) and (B) and the presence of sequential phases of extrusive infill indicates that these volcanic edifices were open. The pipes must have been explosively excavated with the deposition of the resulting material as extra-crater deposits which do not resediment back into the pipe. The xenolith-poor PKs in pipe types (A) and (B) are broadly similar and are probably the product of subsequent magmatic eruptions with variable explosivity. These types of eruptions repeatedly liberate significant volumes of discrete olivines. TK and the association with HK in the related root zones are distinctly different emplacement products. There is ***no*** evidence to show that the pipe was ever open and that the kimberlite infill was extrusive. The high xenolith content of TKs, fractured country rock and association with common HK sheets peripheral to, and in the vicinity of the pipes, must all be significant.

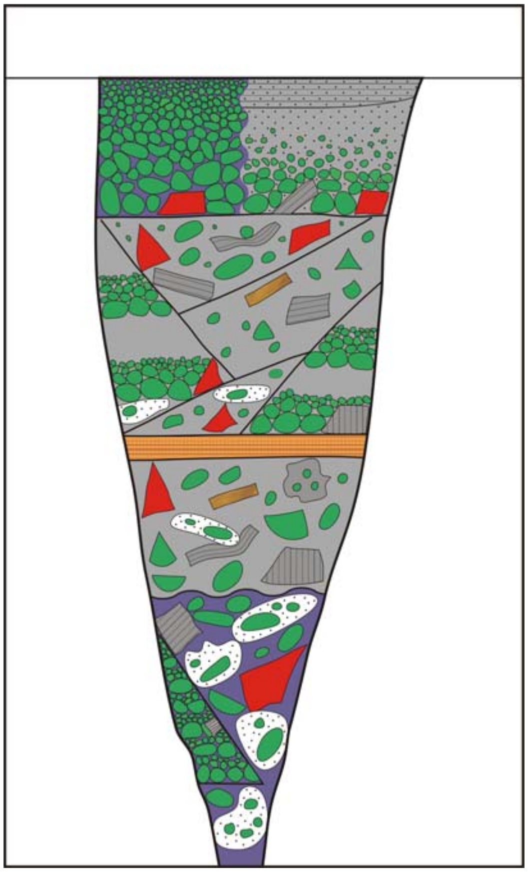

Figure 4 Schematic representation of the dominant pipe infill of the Lac de Gras kimberlites (Nowicki et al. 2004, Graham et al. 1999, McKinlay et al. 1998, unpublished information). Pipe shape from Fig. 2(B), below the erosion surface. The dominant infill is RVK which is composed of variable mixtures of commonly fresh and frequently angular discrete olivine grains (green), xenoliths of shale (darker grey with lines) and less common fresh granitoids (red), minor juvenile lapilli (stippled white), autoliths (darker grey containing olivines) and wood (brown) set in a matrix of mixed disaggregated shale (paler grey). Matrix supported textures and good sorting are common. The RVK infill is characterised by different massive to well-bedded packages displaying variations in xenolith size, type and abundance, olivine size and abundance and proportions of wood (brown) and matrix. Minor kimberlite-poor sediments are present depicted by siltstone (orange) and mudstone (upper ornamented grey, right hand side). Less common PK is composed of similar constituents but with more abundant juvenile material set in a serpentine interclast matrix. Rare mega-graded units occur in the upper parts of the pipes. The left hand side mega-graded bed is composed mainly of discrete olivines in a serpentine matrix (purple) and on the right hand side discrete olivines are mixed with disaggregated sedimentary material (stippled grey).

CONCLUSIONS

Recent data derived from economic kimberlite geology investigations for ongoing diamond exploration and mining projects across Canada have provided substantial amounts of detailed evidence (Figs. 2 to 5) that must be taken into account in establishing emplacement processes. Collation of data on all scales (e.g. Figs. 1-5) are the basis for successfully applying predictive geology to the development of geological models and determination of diamond distributions to establish and mine a mineral resource. This project work continually tests and modifies the compiled geological models and increases the degrees of confidence of them.

The conclusions of Field and Scott Smith (1999; Fig. 1) are supported by subsequent data. At least three types of contrasting types of kimberlite pipes dominate different kimberlite fields. The pipe types (A), (B) and (C) (Fig. 2, in order of discovery in Canada) correspond to pipe class (2), (3) and (1) of Skinner and Marsh (2004), respectively (numbered in the order of discovery in the world with many earlier mined southern African pipes containing TK+HK). Most erupting kimberlite magmas across Canada appear to be similar to the rest of the world. Each of the main constituents, the crystals, melt and volatiles in a kimberlite magma behave differently during near surface emplacement resulting in different pipe infills that must reflect diverse styles of eruption and deposition in the different types of kimberlite. The empirical correlation of contrasting pipe type with different geological settings continues to hold. Skinner and Marsh (2004) propose contrasting eruption processes relating to volatile composition.

ACKNOWLEDGEMENTS

Without the continued cooperation of exploration and mining companies, contributions such as this would not be possible. Unpublished information from the following companies is much appreciated: Stornoway Diamond Corporation and their joint venture partners BHP Billiton Diamonds Inc. and Hunter Exploration Group, BHP Billiton Diamonds Inc., and Mineral Services Canada Inc., Ashton Mining of Canada Inc. and their joint venture partners Encana Corporation, Pure Gold Minerals Inc. and Soquem Inc., De Beers Canada Inc. and their joint venture partners Cameco Corporation, Kensington Resources Limited now a wholly owned subsidiary of Shore Gold Inc., UEM Inc., Mountain Province Inc. and Camphor Ventures.

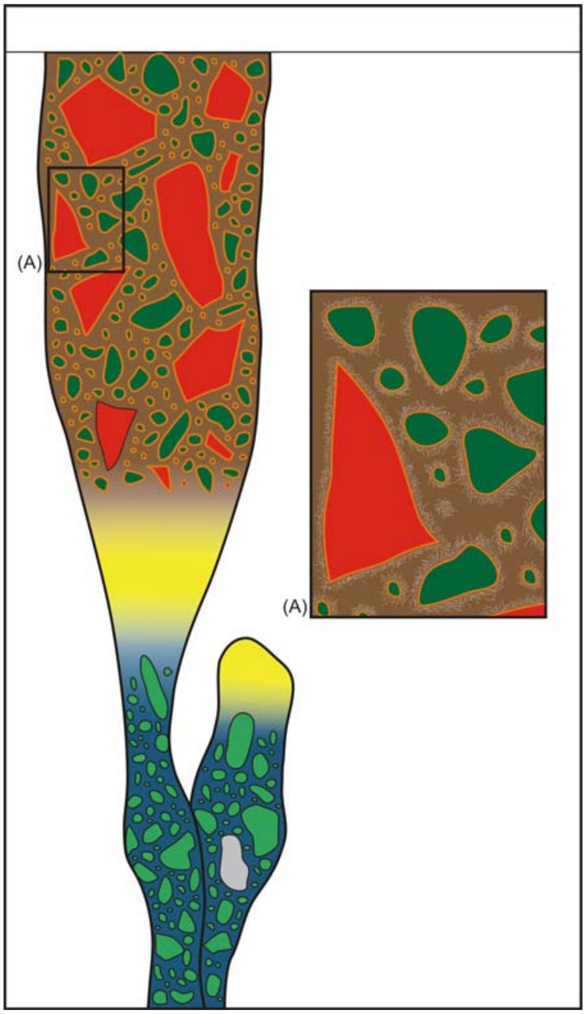

Figure 5 Schematic representation of the pipe infill of the TK-bearing pipes
(Hetman et al. 2004; unpublished information). Pipe shape from Fig. 2(C), below the erosion surface. The root zone is typical HK composed of olivine grains (green), which are often fresh, set in a fine grained but well crystallised groundmass (blue). Granitoid xenoliths are in low abundance. Those present are partly rounded and have reacted with the host magma (pale grey). In contrast the TK contains totally serpentinised olivine (darker green). Angular, fresh granitoid xenoliths are abundant (>30%). Most of these constituents have thin extremely fine grained selvages of kimberlite magma (orange; termed juvenile pelletal lapilli; very different to the pyroclastic juvenile lapilli shown in Figs. 3 and 4). The matrix is composed of serpentine which is susceptible to alteration (brown). The matrix often contains common microlites (white shown in the enlarged inset). Except for the dilution by xenoliths, the distribution of the olivine in the TK is similar to that of the HK. Both the HK and TK are massive with no sorting or bedding. There is a textural transition (yellow) between the HK and TK in a number of pipes in all the fields. The HK to TK transition is gradational with increasing xenolith size and abundance, magmaclastic and microlitic textures, olivine replacement and decreasing degree of crystallinity and xenolith reaction. Multiple phases of kimberlite occur, particularly in the root zone (not shown here).

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LONG ABSTRACTS

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