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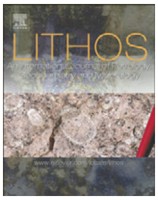

The economic implications of kimberlite emplacement

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ABSTRACT

The economic potential of kimberlite bodies is defined by the volume and diamond content of all their internal units which are summarised in three dimensional geological models. Canadian geological models reveal distinct types of kimberlite bodies characterised by fundamentally different emplacement processes and products. Data for representative samples of Canadian kimberlites are used to show that qualitative and quantitative macroscopic petrography (olivines and xenoliths) are powerful and practical techniques in assessing the economic implications of emplacement within individual phases of kimberlite. Kimberlite bodies result from the near-surface emplacement of multiple discrete batches of mantle-derived magmas, each carrying different diamond populations and, in some instances, subsequent resedimentation processes. Magmas containing ~25 modal % of olivine macrocrysts, the average maximum load of solids that can be carried to surface by a kimberlite magma, have the greatest potential to be significantly diamondiferous. Modifications to the abundance and size distribution of the olivine macrocrysts in each batch of magma commonly occur during emplacement. The modifications to the olivine macrocrysts, which vary with different emplacement processes and products, are mirrored in the macrodiamond content. Dilution by xenoliths is important in predicting diamond contents but it is also reflected in reduced olivine contents. Thus, olivine macrocrysts can act as a proxy for macrodiamonds. The abundance and size distribution data for olivine can improve the prediction of diamond grade and distribution within, and between, kimberlite units. Summary geological models and macroscopic petrography, together, improve the evaluation of newly discovered bodies resulting in enhanced resource estimates and increased degrees of confidence.

1. Introduction

The economic potential of diamond deposits is defined by ore volume and diamond content which are summarised in three dimensional geological models. Resource estimates based on the geological models are used to determine whether the diamonds present can be extracted economically. The mining of primary diamond deposits, which result from the emplacement of magmas and related processes, have dominated world diamond production since the 1960s after modern prospecting techniques led to many discoveries in Russia, Botswana, Australia and more recently Canada (Fig. 5 in Janse, 2007). The volume and diamond content of the pre-emplacement magmas are determined by processes that take place in the mantle and during ascent towards surface. The final volume and diamond content reflect the near-surface emplacement history. A comparison of available geological models that form the basis of resource estimates reveals that distinct types of primary diamond deposits characterised by different shapes and infills reflect contrasting styles of emplacement (e.g. Field and Scott Smith, 1999; Skinner and Marsh, 2004).

In the last two decades many hundreds of kimberlites have been found in Canada leading to the opening of its first diamond mine in 1998 and Canada now ranking in the top five diamond producing countries (e.g. Janse, 2007). In this contribution, Canadian geological models together with qualitative and quantitative macroscopic petrography are used to demonstrate the economic implications of emplacement and that olivine and xenolith abundance and size distribution can be used in the prediction of diamond content. All the significantly diamondiferous bodies in Canada, as well as the majority of primary diamond deposits worldwide, derive from kimberlite magmas and thus other magma types are not discussed.

2. Diamond resource estimation

To establish the diamond potential of newly discovered deposits requires reliable diamond resource estimations based on the following main geological criteria: diamond ore volume (cubic metres/tonnes) and diamond content which is a combination of grade (carats/tonne) and stone value (US$/carat). Given that most kimberlites are subsurface bodies which are difficult to investigate, these criteria are assessed using material typically obtained by different stages and types of evaluation drilling. Each successive stage is more expensive and justified by prior results. Nowicki and Hildebrand (2008) suggest the following costs for three main stages: (i) up to $30,000 for microdiamond-based macrodiamond grade predictions, (ii) up to $1 million for macrodiamond grade estimation bulk samples of approximately 200 tonnes and (iii) up

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to $10 million for diamond value estimation using 1000 carats. Reliable data require representative samples and detailed investigations. Representative sampling and meaningful interpretation of the results must be based on knowledge of the geology of the body, the development of which should start with the discovery. The geology is determined by examining rocks on all scales, megascopic, macroscopic and microscopic. The results are usually presented in terms of three dimensional geological models illustrating the deposit structure to provide the framework for mapping the diamond distribution, which is the basis for the resource estimation and resource classification required for establishing the economic potential of a body and continuation of the project. The development of geological models is based not only on the interpretation of the available geological evidence but, importantly, also on extrapolation of the geology between the points sampled (commonly drillcores) to predict the geology of the whole body and demonstrate resource continuity. The data discussed below help to maximise the value of available samples in the construction of economically relevant geological models.

3. Geological models

Each kimberlite body is unique and, for the purpose of evaluation, resource estimation and mining, requires the development of separate detailed geological models. Numerous and diverse geological models have been developed for many of the recent Canadian discoveries. The geology from the first decade of investigations suggested that (i) these included sheets and at least three distinct classes of kimberlite pipes each dominated by different textural varieties of kimberlite, (ii) one pipe type dominates each field of coeval rocks, (iii) different emplacement mechanisms must have been responsible for the contrasting types of bodies, and (iv) there appears to be a correlation between pipe type and the country rock geology (Field and Scott Smith, 1999). A review of the second decade of data (Scott Smith, 2008b) supported these suggestions and integrated the information in a more detailed summary (Fig. 1). Such summaries can be used to improve evaluation strategies and lead to more reliable results because they (i) provide a norm for comparison or indicate new geological situations, and (ii) act as a guide for the successful extrapolation between data points and application of predictive geology during the development of new geological models.

After discovery, an understanding of the country rock and dominant kimberlite textures can provide early indications of possible body shapes and levels of erosion with obvious implications for the potential ore volumes and thus economic viability. The further development of geological models includes the external shape and the internal geology of each body. Both the nature, and the difficulties in determining these, are different in each type of kimberlite of body (Fig. 1). For example with respect to the external shape of each body which defines the potential ore volume, sheet complexes include many sub-parallel contacts typically defining a number of en-echelon tabular intrusive bodies (Fig. 1c). Pipes resulting from one major volcanic event typically have circular plan view shapes, whereas irregular or elongate shapes may indicate more complex coalescing or cross-cutting bodies. In vertical section, the shape can vary with pipe type (Fig. 1) and establishing the limits of the pipe and/or potential ore, especially in drillcore, can be difficult. For example, in pipe type (a) there can be complicated relationships between pyroclastic kimberlite and poorly-consolidated country rock sediments (Fig. 18g of Scott Smith, 2008a) and in pipe type (c) there are common extensive peripheral country rock breccias and xenolith-rich kimberlites (Fig. 1 of Hetman, 2008).

Virtually all kimberlite bodies, irrespective of their size and shape, are formed by the emplacement of multiple discrete batches of mantle-derived kimberlite magma, each carrying different diamond populations. The emplacement of these discrete magma batches results in different internal phases of kimberlite with contrasting volume, grade and stone value (phase of kimberlite describes the total near surface emplacement products formed from a single batch of magma, not synonymous with facies; a single phase of kimberlite can comprise a variety of facies or units). Each batch of magma usually has distinguishing characteristics (e.g. mantle xenolith and xenocryst content, geochemistry, groundmass mineralogies, country rock xenoliths, textures) which are used to identify phases of kimberlite. Contrasting macrodiamond grades confirm the presence of different phases of

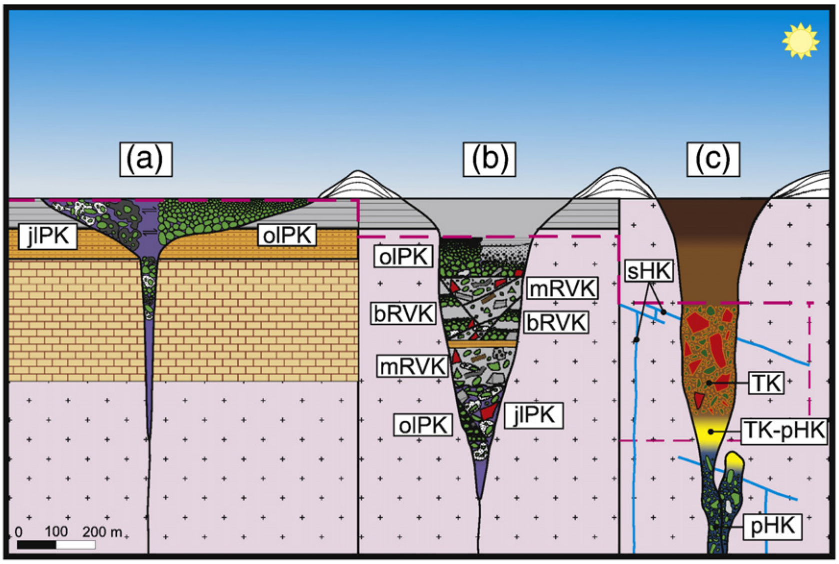

Fig. 1. Schematic representation of the macroscopic components of the different emplacement products infilling the three main types of kimberlite pipes in Canada (from Fig. 4 of Scott Smith, 2008b where more details are provided; see also Fig. 2 below). Dashed line = present surface. Pipe type (a) contains two end members of pyroclastic kimberlite, jlPK and olPK. The jlPK is composed of uniform poorly-sorted amoeboid-shaped juvenile lapilli (melt-bearing pyroclasts composed of olivine and former melt). The olPK is composed of normally-graded well-sorted discrete olivine grains (devoid of melt). The interclast matrix is later cement. Pipe type (b) contains variable types of mud-rich resedimented volcaniclastic kimberlite (RVK) and lesser amounts of pyroclastic kimberlite comparable to the jlPK and olPK in pipe type (a). The RVK includes bedded and massive matrix-supported RVK (bRVK, mRVK, respectively) both with an interclast matrix of mixed disaggregated shale. Pipe type (c) is infilled by tuffisitic kimberlite (TK), the texture of which grades with depth through a transition zone (TK-pHK) to hypabyssal kimberlite within the pipe (pHK). The pHK is composed of olivines set in a well crystallised groundmass. Comparable hypabyssal kimberlite forms common sheets (sHK) in the vicinity of this pipe type. TK is composed of olivines and common angular country rock xenoliths set in a matrix with a different texture to the pHK.