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Kimberlites: Magmas or mixtures?

Michael Patterson [a,*], Don Francis [a], Tom McCandless [b]

[a] Department of Earth and Planetary Science, McGill University, 3450 University Street, Montreal, Quebec, Canada H3A 2A7
[b] Stornoway Diamond Corporation, Suite #800-625 Howe St., Vancouver, British Columbia, Canada V6C 2T6

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ABSTRACT

Although the presence of xenocrystic olivine is widely recognized in kimberlite, there is little consensus about its contribution to the existing estimates for the composition of kimberlite magma. Whole rock geochemistry is critical to the debate regarding the composition of kimberlite magma, however, it has received little attention as an indicator of diamond grade due to conventional thought that diamonds are xenocrysts unrelated to their host kimberlite. The Foxtrot kimberlite Field in Northern Québec is comprised of at least three distinct kimberlite intrusions exhibiting variation in both diamond grade and geochemistry making it an ideal suite with which to test a possible correlation between diamond grade and whole rock composition. Olivine is ubiquitous (30 to 70%) in the Foxtrot kimberlites and exhibits a restricted composition that overlaps that of olivine in harzburgite xenoliths suggesting that the majority of olivine is xenocrystic. Carbonate is also abundant (8 to 35%) in the Foxtrot kimberlites and exhibits magmatic textures requiring that carbon be considered in any petrogenetic model for the Foxtrot kimberlites. Pearce element ratio analysis assuming P as a conserved element indicates that much of the major element variation in the Foxtrot kimberlites can be explained by variable amounts of olivine and orthopyroxene in proportions (~80/20), similar to that of cratonic mantle xenoliths. The xenocrystic nature of olivine requires that the contribution of mantle harzburgite must be removed to constrain the composition of the magma. The calculated magma composition that results from the mathematical removal of olivine and orthopyroxene (80/20) from the whole rock compositions is significantly poorer in MgO (15 wt.%) and silica (~24 wt.%), but CO_2 rich (~17 wt.%) compared to previous estimates for kimberlite magma. The Foxtrot kimberlites are best modelled as mixtures of harzburgite mantle and a relatively carbonate-rich magma. According to this model the correlation between whole rock composition and diamond grade reflects the fact that the diamonds are also xenocrystic and sourced in the harzburgite component.

1. Introduction

The alkaline ultramafic rocks known to host diamonds share the unusual characteristic of being highly enriched in incompatible trace elements, but highly refractory in terms of major element composition. Conventional wisdom in the diamond exploration industry is that diamonds are xenocrysts, unrelated to their host "kimberlites". Because of this philosophical bias, along with their xenolith rich and fragmental nature, the chemical composition of kimberlitic host rocks has received relatively little attention as an exploration tool or as an indication of diamond grade. The present classification of alkaline ultramafic rocks is a confusing mineralogical legacy that is complicated by geographic parochialism. However, a survey of the existing chemical analyses of hypabyssal-facies alkaline ultramafic rocks suggests they can be reliably distinguished on the basis of their silicon and iron contents and that these major element differences have important implications not only for their classification, but also for the nature of their mantle source regions, and even their diamond potential (Francis, 2003; Francis and Patterson, 2009). There are now four independent studies suggesting that there is a relationship between the bulk composition of a kimberlite and its potential diamond grade, with the highest diamond grades associated with the lowest bulk rock iron and titanium contents (Vasilenko et al., 2002; Francis, 2003; Birkett et al., 2004; Hartzler, 2007). This finding is consistent with the rule of thumb of prospectors that kimberlites rich in titanomagnetite do not carry diamonds. This anti-correlation defies conventional wisdom that kimberlites simply transport diamonds to the surface, and are genetically unrelated to their precious cargo. In any case, it appears that a simple whole rock major element analysis is sufficient to uniquely classify "kimberlitic" rocks, and may provide an inexpensive tool for the preliminary evaluation of their diamond potential.

The Foxtrot Kimberlite Field is a diamond play in the Otish Mountains of Québec that is operated by a joint venture between Stornoway Diamond Corporation and SOQUEM. The Foxtrot Kimberlite Field consists of at least 9 different kimberlite pipes, known collectively as the Renard cluster, as well as two other distinct dykes known as the Lynx dyke system and the Hibou dyke (Birkett et al., 2004). The Renard bodies comprise brecciated diatreme cores cut by late stage dykes and sills of hypabyssal

* Corresponding author.
E-mail address: bodhi123@eps.mcgill.ca (M. Patterson).

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kimberlite. There is a wide range of kimberlite compositions and diamond grade in the Foxtrot Kimberlite Field, offering a unique opportunity not only to test the proposed chemical classification of kimberlitic rocks, but also to investigate possible correlations between kimberlite composition and their diamond grade. Our results indicate that kimberlites are best regarded as mixtures whose whole rock composition and diamond grade reflect the type and amount of lithospheric mantle that the Foxtrot kimberlites have entrained.

2. Geologic setting

2.1. Regional geology

The Foxtrot bodies were emplaced into Archean metamorphic rocks of the eastern Superior Province (Fig. 1). The northern portion of the property is underlain by North–Northwest trending, plutonic and gneissic terranes (varying in width from 70 to 150 km) defined by metamorphic grade, lithology, and aeromagnetics (Clements and O'Connor, 2002). The basement gneiss near the Foxtrot bodies has been metamorphosed at upper amphibolite to lower granulite facies conditions in late Archean time (Birkett et al., 2004). Pleistocene glaciation of the Foxtrot area has left thick till deposits, lag deposits of glacially transported boulders, and large glacial erratics. Among the glacial erratics are a large number of kimberlite boulders, which were used as an exploration tool to locate kimberlite dykes on the property.

A perovskite U–Pb age of 631.6 ± 3.5 Ma has been obtained for a hypabyssal dyke cutting the Renard 1 pipe and composite age of 640.5 ± 2.8 Ma for three hypabyssal dykes cutting the Renard 2 and 3 pipes (Birkett et al., 2004; Fitzgerald et al., this issue). This is similar to the 629 ± 29 Ma age reported for the Wemindji kimberlites that are approximately 400 km to the West of the Foxtrot Kimberlite Field. A significantly younger age of 522 ± 30 Ma was obtained, however, on groundmass ilmenite in the Lynx dyke (McCandless et al., 2008). Other nearby kimberlite occurrences in the Otish Mountains include the Lac Beaver and Tichegami kimberlites that occur approximately 70 km to the South of the Foxtrot Kimberlite Field with an age of 551 ± 3 Ma (Girard, 2001; Moorhead et al., 2002; Letendre et al., 2003).

2.2. Detailed geology

The Foxtrot Kimberlite Field is comprised of at least three distinct kimberlite occurrences in terms of emplacement morphology, geochemistry, and mineralogy. The field is dominated by nine diatreme pipes that form the Renard cluster in the eastern portion of the field (Fig. 1). These pipes are individually elongated along the north north-west trend collectively defined by the pipes. The pipes are primarily composed of transitional to diatreme facies kimberlite that is intruded along facies boundaries and pipe margins by late stage hypabyssal kimberlite dykes (Birkett et al., 2004; Fitzgerald et al., this issue). The Lynx dyke system is located two km to the West of the Renard cluster, but shares the north north-west orientation of the Renard pipes, whereas the Hibou dyke system, located between the Renard cluster and the Lynx dyke system, has an approximate east–west orientation (Fig. 1). Other kimberlite occurrences related to the Foxtrot Kimberlite Field

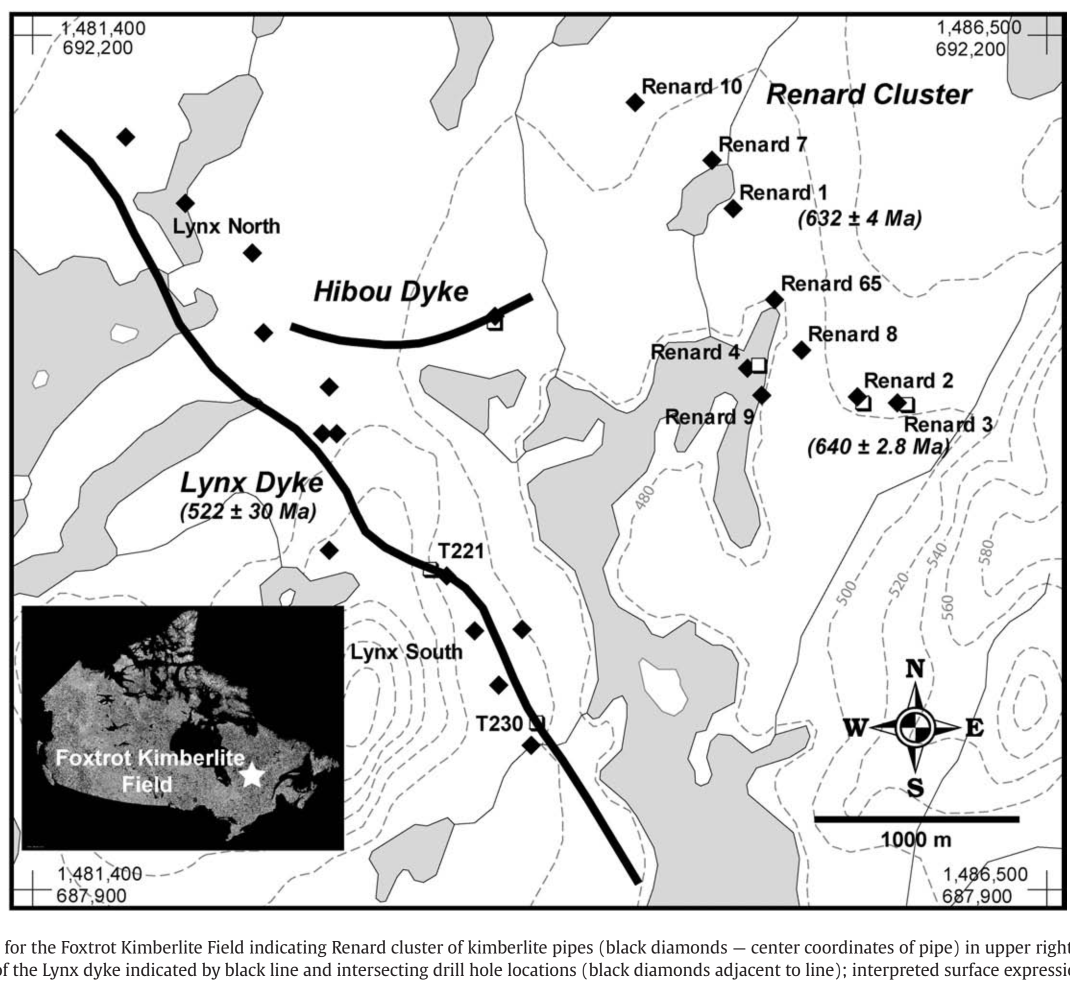

Fig. 1. Location map for the Foxtrot Kimberlite Field indicating Renard cluster of kimberlite pipes (black diamonds — center coordinates of pipe) in upper right of map; interpreted surface expression of the Lynx dyke indicated by black line and intersecting drill hole locations (black diamonds adjacent to line); interpreted surface expression of the Hibou dyke indicated by black line. Open trench or drift sample site indicated by open squares. Foxtrot Kimberlite Field location shown on image of Canada (inset).