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Diamond preservation in the lithospheric mantle recorded by olivine in kimberlites

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Introduction

Diamond exploration is a multifaceted operation that relies on combinations of multiple geophysical and geochemical methods (Kjarsgaard et al., 2019). The composition of diamond indicator minerals (DIMs) in kimberlites, including mantle-derived garnet, clinopyroxene and chromite, provides important constraints on the diamond potential of the lithospheric mantle traversed and entrained by kimberlites (Gurney et al., 1993; Nowicki et al., 2007), including the thickness of the lithospheric roots (Grutter, 2009) and, therefore, of the diamond window. DIMs also provide indications of the extent of depletion vs metasomatic enrichment of the lithospheric mantle, as it is well established that diamonds brought to surface by kimberlites preferentially reside in compositionally depleted lithospheric mantle roots (Gurney et al., 1993; Nowicki et al., 2007). The connection between melt-metasomatism of the deep lithosphere and diamond potential of kimberlites is well-established empirically (Griffin and Ryan, 1995), but its geological context is not well understood, e.g., What is the origin and composition of these metasomatic melts? When did this metasomatism affect the lithospheric mantle? This work targets this knowledge gap and explores a new method to enhance the diamond exploration toolbox.

Background and rationale

Kimberlites are complex hybrid rocks that contain components of magmatic, hydrothermal and xenocrystic origin. Olivine is the main constituent of fresh kimberlite rocks (Mitchell, 1973) and is generally zoned between xenocrystic cores derived from disaggregation of lithospheric mantle wall rocks, and magmatic rims (Giuliani, 2018). The olivine cores do not simply represent typical mantle peridotites, but may also be sourced from other lithologies (e.g., megacrysts; sheared peridotites) that have experienced metasomatism by precursor kimberlite melts. It is indeed well established that the eruption of kimberlite magmas is preceded by 'priming' of lithospheric mantle conduits by earlier failed pulses of kimberlite melt (Giuliani et al., 2014).

The average Mg# [atomic proportions of Mg/(Mg+Fe)] of xenocrystic olivine cores is directly correlated to the average Mg# of olivine rims in kimberlites on a global (Giuliani et al., 2020) and regional scale (Sarkar et al., 2021; Tovey et al., 2021). This correlation, combined with extensive petrographic and experimental evidence of assimilation of entrained lithospheric mantle material by kimberlites (Mitchell, 2008; Kamenetsky et al., 2009; Soltys et al., 2016), suggests that the composition of kimberlite melts at surface is directly related to the composition of lithospheric mantle wall rocks which interacts with kimberlite melts *en route* to surface (Giuliani et al., 2020). It further establishes that the more intensive the metasomatism, the more Fe-rich is the composition of magmatic olivine. Therefore, olivine chemistry provides a direct link between kimberlite melt composition and lithospheric mantle wall rocks, including the extent of kimberlite-related metasomatism of the lithospheric mantle traversed by pulses of kimberlite magma that reach the surface.

Recent experimental work by Fedortchouk et al. (2022) has confirmed existing evidence (e.g., Robinson et al., 1989) that interaction of diamonds with carbonate-rich melts akin to kimberlites at lithospheric mantle depths leads to diamond resorption. Here, we test whether a correlation exists between olivine compositions and diamond grades in kimberlites worldwide, with the poviso that the composition of olivine in kimberlites constrains the extent of kimberlite-related metasomatism of the (diamond-bearing) lithospheric mantle roots. If this hypothesis is correct, we expect to observe lower diamond grades in kimberlites that sample lithospheric mantle wall rocks that have been extensively metasomatised by precursor kimberlite melts and, therefore, contain olivine with low (average) Mg# values.

Results

Building up on the compilation of Giuliani et al. (2020), we have assembled a revised database that includes new electron microprobe analyses of olivine in 12 kimberlites from Russia, Canada, Brazil and South Africa, and additional results from other localities published since the previous compilation. This new dataset (Giuliani et al., 2023) confirms that the average Mg# of olivine cores in kimberlites (and also diamondiferous cratonic lamproites; see Sarkar et al., 2022) is directly correlated with the average Mg# of olivine rims. Of the 100 localities for which olivine data are now available, 74 have associated diamond grades (e.g., run of mines; exploration data). Comparison of average Mg# of either olivine cores or rims (which are linearly correlated) with diamond grades indicates that high diamond grades (>50-100 cpht or carats per hundred tonne) are exclusively associated with high-Mg# olivine, i.e. >90 for olivine cores, ≥89 for olivine rims. Conversely, the diamond grades of kimberlites featuring low-Mg# olivine are always low (<20 cpht). It should be noted that low diamond grades can also occur in kimberlites with high-Mg# olivine.

Discussion and implications

The correlation between average olivine Mg# (cores or rims) and diamond grades confirms our working hypothesis that kimberlite-related metasomatism is detrimental to diamond preservation. This finding provides a sound explanation for the empirical observation, based largely on garnet xenocryst compositions (Gurney et al., 1993; Griffin and Ryan, 1995), that melt-metasomatism of the lithospheric mantle leads to diamond destruction.

This study highlights that the major element composition of olivine in kimberlites represents a new inexpensive tool for diamond exploration. This tool does not replace other geochemical approaches such as analyses of garnet, but can be used to rapidly assess the likelihood of high diamond grades in a kimberlite based on the extent of kimberlite metasomatism of the lithospheric mantle roots. An important caveat is that olivine compositions are relatively invariant in kimberlite pipes and clusters of kimberlites, whereas diamond grades vary on every scale. Hence, olivine compositions provide constraints on the likelihood of diamond preservation in the lithospheric mantle, but do not allow prediction of the influence of other local-scale processes which impact diamond grade such as pre-existing diamond contents in the wall rocks, sampling efficiency by kimberlite melts, sorting of entrained mantle cargo during kimberlite ascent and emplacement, dilution by country rocks, etc. Nonetheless, used in combination with other geological constraints such as the depth of the lithosphere retrieved from mantle xenolith and xenocryst data, the composition of olivine can provide an important tool for assessing the diamond potential of a kimberlite pipe or cluster before undertaking more detailed investigations.

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