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Origin of olivine in kimberlite: Phenocryst or impostor?

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ABSTRACT

Kimberlite hosts two populations of olivine that are distinguished on the basis of grain size and morphology; the populations are commonly described genetically as xenocrysts and phenocrysts. Olivine xenocrysts or macrocrysts are thought to derive from disaggregation of mantle xenoliths whereas the smaller, euhedral olivine crystals are presumed entirely cognate to the kimberlite melt. Recent studies of zoning patterns of euhedral olivine in kimberlite have, however, cast doubt on the actual origins of the smaller olivine crystals. Here, we elucidate the nature and origins of the textural and chemical zonation that characterize *both* populations of olivine: macrocrysts (olivine-I) and euhedral crystals (olivine-II). Specifically, we show that both olivine-I and olivine-II feature chemically distinct overgrowths resulting from heterogeneous crystallization onto pre-existing olivine xenocrysts. Our analysis limits the total volume of olivine crystallized during transport to ≤5% in contrast to previous estimates of ~25%. The reduced extent of olivine crystallization allows for closer reconciliation of crystallized olivine compositions and estimates of Mg#s for primitive kimberlite melts. It also places constraints on processes involving orthopyroxene assimilation by kimberlite melt. If olivine crystallization and orthopyroxene assimilation are coupled, then orthopyroxene assimilation is limited to ~7%. Larger masses of orthopyroxene assimilation (i.e. 25%) are possible only if kimberlite magmas originate at super-liquidus (>100 °C) conditions and sub-equal amounts of olivine crystallization occurs.

1. Introduction

Olivine is the dominant phase in all kimberlite bodies and a petrogenetic model for kimberlite must, therefore, include a complete explanation for its origins. The olivine hosted by kimberlite forms two populations that are distinguished on the basis of grain size and morphology (Clement et al., 1977; Skinner and Clement, 1979). The volumetrically important population comprises medium to coarse-grained, rounded to sub-rounded olivine grains, and are referred to as macrocrysts (Clement, 1982). The second population features medium to fine-grained (<0.5 mm), euhedral to subhedral olivine grains and are commonly designated as phenocrysts. For over 30 years the two populations of olivine found in kimberlite have been ascribed different origins, as encapsulated by their labels: the macrocrysts are considered xenocrystic whilst the phenocrysts are assumed to have crystallized from the kimberlite melt (Jerram et al., this issue; Field et al., this issue).

Kimberlite from the Diavik Diamond Mine, N.W.T., Canada contains olivine with rounded to sub-rounded cores featuring distinct overgrowths of later crystallized olivine. In all samples we observe overgrowths on *both* 'macrocrystic' and 'phenocrystic' olivine crystals. This paper elucidates the origins of these overgrowths, and explores the implications of their occurrence. Our analysis suggests that virtually all olivine within kimberlite has a xenocrystic origin and derives from disaggregated mantle peridotite. This substantially reduces the perceived amount of olivine crystallization during transport relative to previous estimates (up to 25%; Clement, 1982; Scott Smith, 1996; Harris et al., 2004; Mitchell, 2008). The reduced extent of olivine crystallization has important implications on: i) estimates of primitive kimberlite melt compositions (e.g. Price et al., 2000; Patterson et al., this issue), and ii) the extent of orthopyroxene dissolution and melt modification attending kimberlite ascent (e.g. Mitchell, 1986).

2. Kimberlite sample suite

The Diavik diamond mine is located within the Lac de Gras area of the Slave craton, approximately 300 km north-east of Yellowknife in the Northwest Territories, Canada. Four kimberlite pipes are currently in the Diavik mine plan (A154N, A154S, A418, A21) and are Eocene in age (55–56 Ma; Heaman et al., 2004). We document the textural and compositional attributes of olivine occurring in kimberlite dykes and volcaniclastic kimberlite units from Diavik. Five samples of coherent kimberlite are from dykes associated with three of the Diavik pipes (Table 1). In these samples olivine is not serpentinized, not even along grain margins or internal factures. Whole rock chemical compositions for the samples are given in Table A1. In terms of the major constituents (SiO_2, MgO, CaO and FeO (T)), the compositions are similar to other analyses of 'fresh'

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Table 1
List of samples and descriptions of source, deposit type and olivine content.

Label[a]	Kimberlite pipe	Unit	Facies	Vol.% olivine	Reference
1	A154 north	Late dyke	Coherent	41	Moss et al. (2008)
2	A154 north	Late dyke	Coherent	40	–
3	A154 north	Late dyke	Coherent	50	–
4	A154 south	Late dyke	Coherent	45	–
5	A21	Late dyke	Coherent	40	–
6	A154 north	MVK	Volcaniclastic	70	Moss et al. (this issue)
7	A154 north	GK	Volcaniclastic	53	Moss et al. (this issue)

[a] 1:A154N_08_pet02; 2:A154N_10_12; 3:A154N09_07; 4:A154_35_03; 5:A21_GT03_01; 6:GTH_75_17_01; 7:A154N_340_GK_B02; MVK = Massive volcaniclastic kimberlite; GK = Graded kimberlite.

kimberlites (Dawson, 1994; Price et al., 2000; Caro and Kopylova, 2004). Two samples were collected from two distinct volcaniclastic kimberlite deposits (Table 1) described previously by Moss et al. (2008).

3. Petrography

Samples of coherent kimberlite contain 40–50 vol.% olivine (Table 1), and on the basis of grain size and morphology the olivine constitutes two distinct populations: A) medium to coarse-grained (1 mm to 10 mm), rounded to sub-rounded crystals (olivine-I, Fig. 1A), and B) fine-grained (<1 mm), euhedral to subhedral crystals (olivine-II, Fig. 1B). The samples also contain garnet (<2%), clinopyroxene (<2%) and orthopyroxene (<1%). The groundmass mineralogy includes equant oxides consisting of Cr-spinel with overgrowths of ulvöspinel-spinel that have dark-brown rims of transparent serpentine. Groundmass minerals identified petrographically, in order of decreasing abundance, include: olivine, opaque oxides, monticellite, apatite and perovskite. These minerals are commonly euhedral and are enclosed by a carbonate–serpentine mesostasis. Occasionally, carbonate is found to poikilitically enclose groundmass minerals and xenocrysts. In most samples, monticellite is only present within

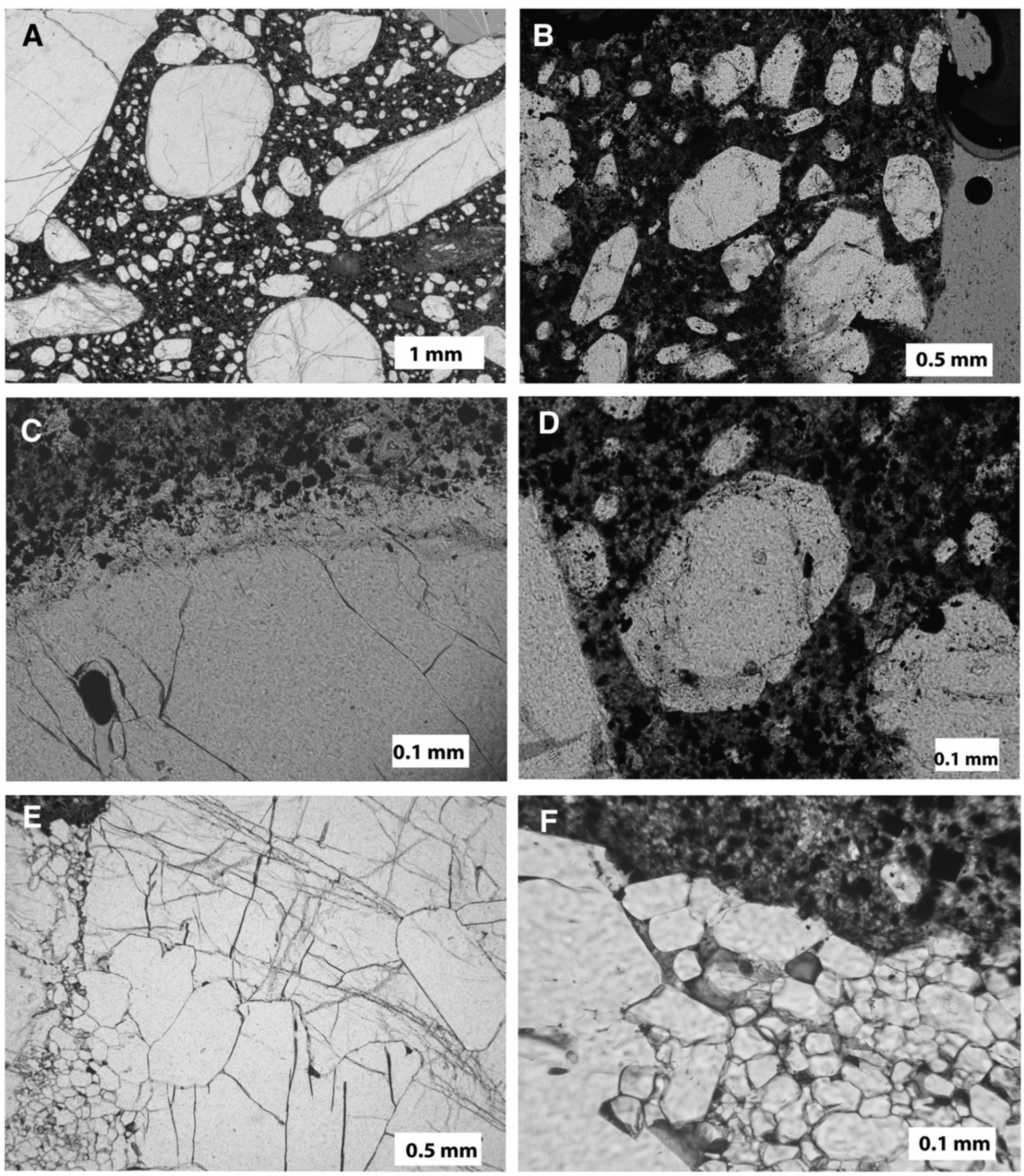

Fig. 1. Photomicrographs of olivine from Diavik kimberlite deposits, showing: A) xenocrystic olivine (olivine-I) comprising anhedral, rounded to sub angular, inequigranular crystals, B) "phenocrystic" olivine (olivine-II) identified as smaller (<1 mm), euhedral to subhedral crystals, C) overgrowth on olivine macrocryst (olivine-I) defined by increase in concentration of inclusions, D) olivine-II crystal showing euhedral overgrowth on rounded core, E) mantle xenolith containing mm-scale band of polycrystalline recrystallized olivine grains, F) enlarged view of polycrystalline recrystallized olivine showing characteristic grain size (<1 mm) and subhedral to euhedral habit.