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Diversity of crystallization conditions of hypabyssal and coherent kimberlites recorded in diamond surface textures

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Introduction

The hybrid nature and high degree of alteration of kimberlites complicate estimation of melt composition and crystallization conditions of kimberlite magma (Giuliani and Pearson 2019). Diamonds are part of the load of mantle material carried by kimberlite to the surface. During this transportation diamonds react with kimberlite magma and develop a variety of surface dissolution features, which reflect the conditions in the host kimberlite magma. Diamonds from different types of volcanoclastic kimberlite lithologies (VK) show low-relief dissolution features reproduced in experiments with C-O-H fluid supporting fluid-driven explosive emplacement of these units (Fedortchouk 2019). Composition of this fluid can be deduced from the geometry of trigonal etch pits on diamonds. However, diamonds from coherent (CK) and hypabyssal (HK) kimberlites display deep corrosion sculptures, cavities, and sharp features, which not only greatly vary between and within kimberlite units but most importantly display a strong association with certain kimberlite types (Fedortchouk 2019). Less explosive emplacement of HK/CK units suggests development of these features on diamonds in fluid-deficient magma. In this study we use high-pressure (P) - temperature (T) experiments to test diamond dissolution in volatile-undersaturated melts and the effect of P-T conditions and melt composition on diamond dissolution. We use our experimental results to examine diamonds from different CK and HK units from Ekati kimberlites (Northwest Territories, Canada) to gain insights to their conditions of formation.

Experimental Results

Diamond dissolution experiments were conducted using piston-cylinder apparatus at 1050 – 1200ºC at 0.5 – 2 GPa in synthetic kimberlite mixtures which produced volatile-undersaturated melts with a range of SiO_2 from 12.5 to 49.5 wt%, CO_2 from 1 – 30 wt%, and H_2O from 1.5 – 12 wt%. Our experiments produced irregular and corrosive diamond dissolution features strikingly different from those observed in experiments with C-O-H fluid (Arima and Kozai 2008; Fedortchouk, et al. 2007) and resembling diamond features in CK and HK (Fedortchouk, et al. 2017). T and P play the major role in controlling the dissolution style (Fig. 1). We also observed an increase in the sharpness of diamond surface features towards lower P and higher T. The effect of melt composition is less noticable, however increase in H_2O and SiO_2 content results in smoothing of surface textures, whereas higher CO_2 content increases their sharpness.

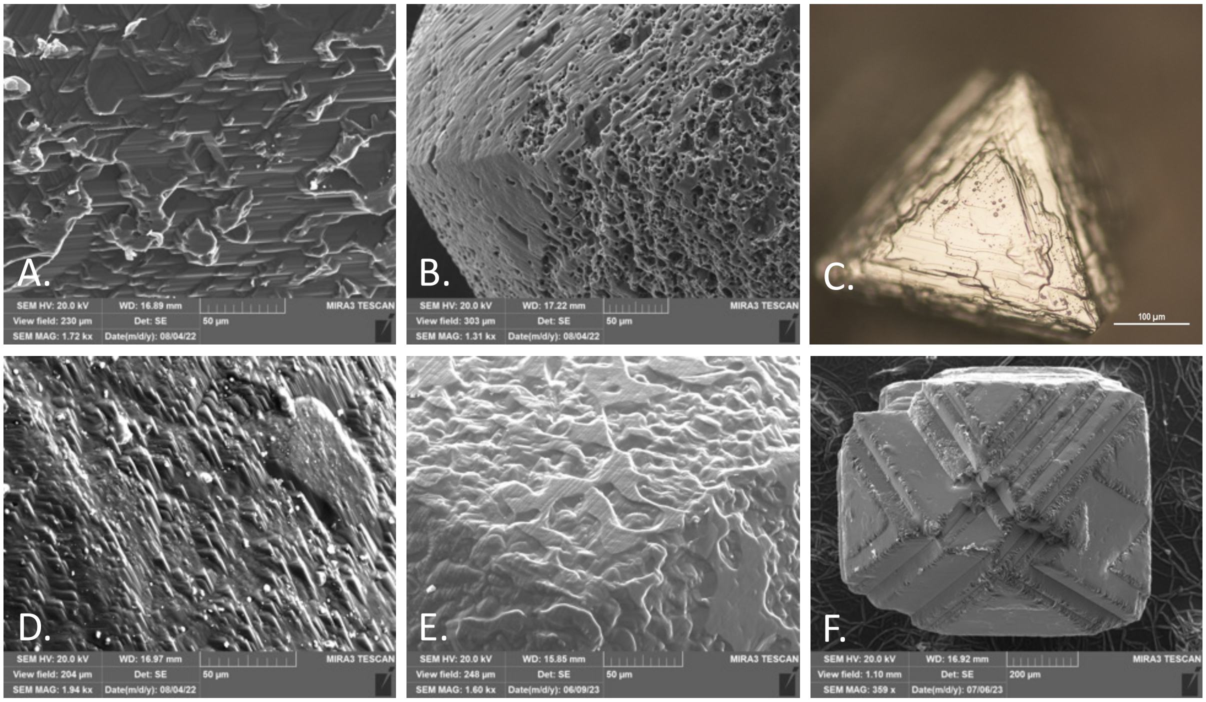

Figure 1: Styles of diamond dissolution in experiments with silica-carbonate melts with 1.5-3 wt% H_2O. A. 1200ºC at 1 GPa: corrosion sculptures common for HK root zones of complex pipes (e.g. BK1, Orapa cluster). B. 1200ºC at 0.5 GPa: intense etching with deep channels (occurr in VK and HK). C. 1100ºC at 1 GPa: flattened "shallow depressions" resemble features in some HK. D. 1100ºC and 0.5 GPa: sharp frosting common in pipe-infill CK (e.g. Grizzly, Ekati Mine). E. 1100ºC at 1 GPa with 12.5 wt% H_2O (reaching fluid-saturation): heavily corroded textures different from features in HK/CK. F. 1050ºC at 0.5 GPa: positive trigons on {111} faces, imbricate wedges and transverse hillocks along crystal edges (rarely found on natural diamonds).

Resorption of natural diamonds

We studied 862 micro-diamonds from 18 kimberlites in Ekati Mine area under a petrographic microscope and selected 207 octahedra and tetrahexahedra (THH) crystals without significant breakage, from which representative 150 crystals with notable resorption were further studied with a Field-Emission Scanning Electron Microscope. The data were combined with our previous data from diamonds from Ekati (Fedortchouk, et al. 2010) and from two bodies in Orapa kimberlite cluster, Botswana (Fedortchouk et al., 2017). We compared resorption features on diamonds from VK and CK units within the same kimberlite body in Misery and Aaron kimberlites (Ekati) and BK1 kimberlite (Orapa cluster, from Fedortchouk et al., 2017). We also compared diamond resorption in CK-filled kimberlites (Grizzly, Pigeon and Anaconda) to diamond resorption in VK-filled kimberlites (Cobra, Crab, Koala, Koala North, and Lioness).

Diamonds from Misery Main pipe, infilled predominantly with VK, show a high proportion of rounded THH diamonds with low-relief glossy surfaces, often featureless or with thin terraces and smooth hillocks (Fedortchouk et al. 2010). Misery East is one of the numerous small kimberlite bodies surrounding the Misery Main pipe, which consists entirely of HK and is interpreted to be one of the precursor hypabyssal intrusions (Mustafa, et al. 2003). THH diamonds from Misery East are completely covered with hillocks, often showing areas with sharp corners, sharp irregular asperities, deep channels, shallow depressions, and tetragons in [100] direction. In Aaron kimberlite, a distinct feature of THH diamonds from HK unit (10 diamonds) is fine corrosion along the rounded resorbed crystal edges and presence of deep channels. These features are absent on the 17 diamonds from the VK unit, which show low relief features on THH crystals with few smooth hillocks and tetragons in [100] direction. The features observed on Misery East and Aaron diamonds from HK units are similar to the products of our experiments at 1200°C (0.5 and 1 GPa) and 1.5-7 wt% H_2O.

Different resorption features cover diamonds from Grizzly pipe (pipe infilled with extrusive CK). These diamonds show sharp pointy frosting and corners, often with "islands" of other frosting, which resemble products of our experiments at 1100°C and 0.5 GPa with 1.5-3 wt% H_2O. The corrosion sculptures previously observed in the CK unit from BK1 kimberlite in Orapa cluster resemble experimental products at 1200°C and 1 GPa with 1.5-3 wt% H_2O. THH and resorbed octahedra from Pigeon (11 diamonds from HK and 3 diamonds from Crater unit) and Anaconda (2 diamonds from HK) revealed no difference between lithological units. All THH faces show low-relief resorption but with hillocks showing sharp points, frequent deep etch channels, and areas with tetragons in [100] direction.

Application to kimberlite magmatism

Diamond resorption investigated in this study must be occurring at depth around ~15 km (0.5 GPa) before final emplacement of the magma into a pipe or a dyke. This is because resorption at shallower depth produces positive trigons extremelly rare for natural diamonds. At this stage of kimberlite ascent, the part (pulse) of the magma column producing VK units has abundant C-O-H fluid driving the explosive eruption. Volatile saturation at this depth for melts with ~25 wt% SiO_2 would occur at ~4 -7 wt% of H_2O and ~15 – 22 wt% of CO_2 (Moussallam, et al. 2016). The part (pulse) of the magma column erupting as one of the HK or CK units, has water content ~ < 3 wt% H_2O and no fluid phase, which either did not reach saturation or was lost to the wall-rocks. Diamond resorption in kimberlite magma forming HK in the root zone of complex kimberlite pipes records 1200°C at 1 GPa and fast eruption from this depth, whereas in Ekati pipes infilled with CK material (Grizzly) resorption records 1100°C at 0.5 GPa indicating slower ascent of this magma. Diamond resorption styles in small hypabyssal kimberlite bodies, such as Misery East precursor intrusion and HK unit along the south-east wall of Aaron pipe suggest the temperature of kimberlite magma is 1200°C (at 0.5 and 1 GPa).

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