Features of apatite in kimberlites from Ekati Diamond Mine and Snap Lake, Northwest Territories, Canada: modelling of kimberlite composition

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Introduction

Volatile proportions (H_2O, CO_2, F, Cl) and timing of fluid exsolution have important implications for kimberlite melt compositions, evolution and eruptive processes. The timing of fluid exsolution from kimberlite melts can affect the resorption and preservation of diamonds carried to the surface (Fedortchouk et al. 2010).

Apatite, $Ca_5(PO_4)_3(F,Cl,OH)$, is a common groundmass mineral in kimberlites, crystallizing together with serpentine and carbonates (Malarkey et al. 2010) and is often used as an indicator of volatile behaviour in igneous rocks (Miles et al. 2013; Piccoli and Candela 1994). Apatite is a major host of halogens, rare earth elements (REE's) and Sr, whose concentrations are sensitive to magma fractionation and the presence and composition of fluid during magma crystallization and post-magmatic hydrothermal alteration. This study uses groundmass apatite to evaluate the volatile history of kimberlites with various eruption styles using kimberlite pipes from Ekati Mine and Snap Lake mine kimberlite dyke. We show textural and compositional variations of apatite in neighbouring kimberlite bodies and the mineralogical in Snap Lake dyke. Concentrations of REE and other trace elements combined with experimentally derived partitioning coefficients of these elements from the literature between apatite and silicate melt, carbonate melt and aqueous fluid help us to examine the composition of each studied kimberlite magma.

Kimberlite	Abundance	Size (μm)	Habit	Zonation
Leslie (CK)	abundant	5-60	euhedral	patchy
Grizzly (CK)	intermediate	< 10	subhedral	core-rim
Panda (RVK)	intermediate	20-100	subhedral	oscillatory
Beartooth (RVK)	v. low			
Misery (VK)	v. low			
Koala (VK)	intermediate	10-150	anhedral	core-rim
Snap Lake (phlogopite-poor)	abundant	10-100	Type 1, 2	core-rim
Snap Lake (phlogopite-rich)	abundant	20-50	Type 3	concentric

Table 1: Features of apatite in six Ekati Mine kimberlites and in Snap Lake dyke. (Type 1,2,3 refer to the apatite types in Snap Lake, CK – coherent kimberlite, RVK – resedimented volcaniclastic kimberlite).

Samples and Methods

This study used two thin-sections from each of the six Ekati Mine kimberlites (Koala, Panda, Leslie, Misery, Grizzly and Beartooth). Different geological features (Table 1) and diamond populations (Fedortchouk et al. 2010) of these kimberlites suggest different volatile and eruption histories. 32 thin-sections from Snap Lake kimberlite dyke represent six mineralogical zones ranging from fresh phlogopite-poor to altered and highly-altered phlogopite-rich kimberlite. We used scanning electron microscopy (SEM) and cathodoluminescence (CL) to examine growth and resorption zonation in apatite; wavelength dispersive spectroscopy (WDS) for microprobe analyzes of major and minor

elements, and laser ablation inductively coupled plasma mass spectrometry (ICP-MS) for trace element analyzes. REE patterns of apatite discriminate between xenocrystal apatite from country rock and kimberlitic apatite.

Apatite Types

Apatite grains are present in four of the six Ekati kimberlites: Leslie, Panda, Grizzly and Koala. Leslie has abundant euhedral apatite with many monticellite inclusions, patchy zonation (Fig. 1a) and high content of LREE and Sr (Fig. 2a). Apatite in Panda is subhedral with complex oscillatory zonation rich in LREE (Figs. 1b, 2a). In Grizzly, resorbed apatite xenocrysts with low LREE and Sr are surrounded by resorbed kimberlitic apatite with high REE and Sr (Figs. 1c, 2a). Apatite in Koala are abundantly preserved, xenocrystic (Fig. 2a) and have inherited core-rim zonation (Fig. 1d).

In Snap Lake kimberlite dyke, three textures of apatite were observed and classified as separate "Types". They all have similar REE and trace element patterns, with exchange of Sr in the case of lower REE concentrations. Snap Lake apatite grains show less fractionated LREE-HREE patterns than Leslie and Panda apatites (Fig. 2). Fresh, phlogopite-poor kimberlite lithofacies have abundant radial aggregates of acicular or columnar apatite crystals (Type 1, Fig. 1e) with strong zoning revealed in CL and the lowest concentration of REE in Snap Lake. This is accompanied by prismatic zoned apatite in carbonate veins (Type 2). Altered, phlogopite-rich kimberlite have prismatic euhedral apatite with well-formed growth zoning (Type 3, Fig. 1f), and higher content of REE, U, HFSE and Ti (Fig. 2b).
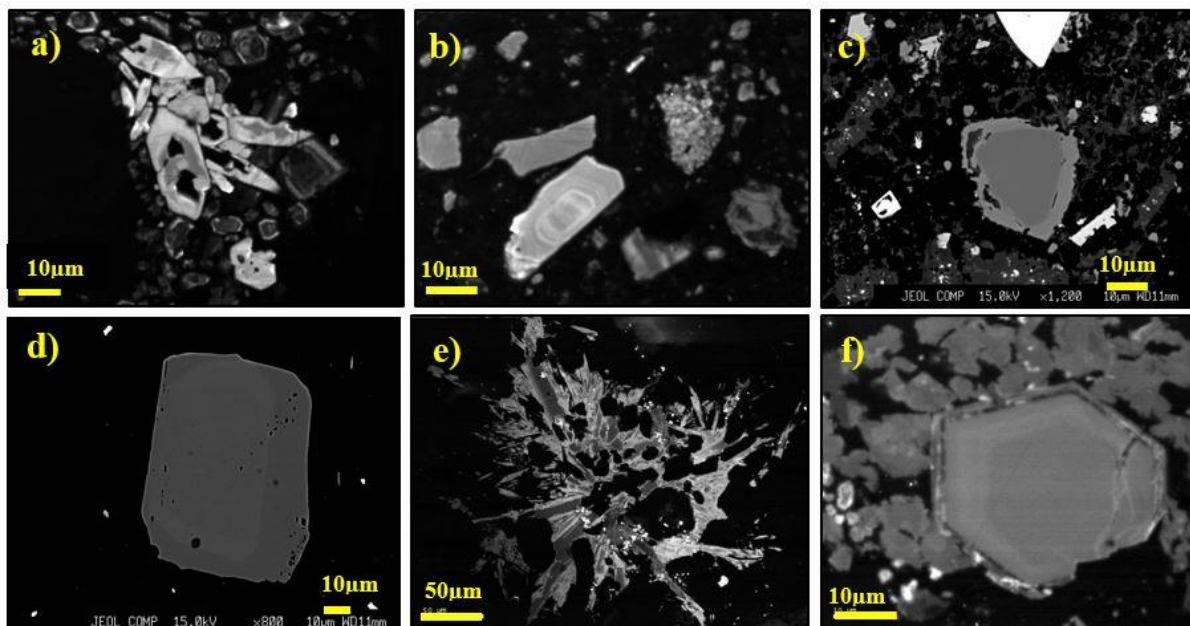

Figure 1: Apatite textures from Ekati kimberlites a) Leslie, CL image, b) Panda, CL image, c) Grizzly, BSE image, d) Koala, BSE image, e) Snap Lake Type 1, CL image, and f) Snap lake Type 3, CL image.

Apatite as an indicator mineral

Our data shows variation in both: preservation of xenocrystal apatite from country rock and crystallization of kimberlitic apatite in the six neighbouring kimberlites from Ekati Mine. Xenocrystal apatite is well-preserved in Koala and partially preserved in Grizzly. If present initially, it was completely dissolved by Leslie, Panda, Misery and Beartooth magmas, and in Snap Lake. Apatite was most stable in Koala and only slightly rounded by dissolution. In Grizzly, rounded resorbed xenocrystal cores were overrown by the rims of kimberlitic apatite, which also show resorption. Fig. 2a shows that the most distinct changes in the composition of crustal-derived apatite which resided in kimberlite magma are increase of LREE relative to MREE, HREE and Sr (Fig. 2a). This could allow the use of apatite as a kimberlite indicator mineral during prospecting.

Crystallization of apatite from kimberlite magma is controlled by reaching phosphorous saturation and only occurred in Leslie, Panda and Grizzly (as rims on xenocrysts). Preservation of xenocrystal apatite in Koala could explain lower phosphorous content in the magma, insufficient for the crystallization of kimberlitic apatite. However, in Misery and Beartooth, phosphorous saturation was not reached. Phosphorous saturation required for apatite saturation also depends on temperature and melt composition (SiO_2, CaO; Watson, 1980; Tollari et al. 2008). Apatite crystallization could reflect variation in assimilation of crustal xenoliths by different kimberlite magmas, which alter both P_2O_5 and SiO_2 in the melt, triggering or impeding the crystallization of apatite. In Snap Lake, all apatite is kimberlitic (Fig. 2b), crystallizing either from the melt or from deuteric kimberlite fluids. Identical composition of radial aggregates of acicular apatite Type 1 and apatite Type 2, found in post-magmatic veins that cut through olivine macrocrysts, point to their common post-magmatic origin. Euhedral zoned Type 3 apatite found in phlogopite-rich lithologies shows similar REE patterns, but has higher REE content and much lower Sr/La ratio than Type 1 and 2. Its Sr/La ratio is similar to apatite from Ekati samples. The higher H_2O activity in phlogopite-rich lithologies could be responsible for earlier apatite saturation (Tollari et al. 2008). We obtain partition coefficients (D) for REE and other trace elements for apatite using our LA-ICPMS data and bulk rock compositions for the same kimberlites from the literature (Nowicki et al. 2004) and compare them to experimentally determined D values for silicate melt and carbonate melt from the literature (Prowatke and Klemme, 2006). Our data for Leslie, Grizzly, and Panda best agree with apatite crystallization from a silicate melt.
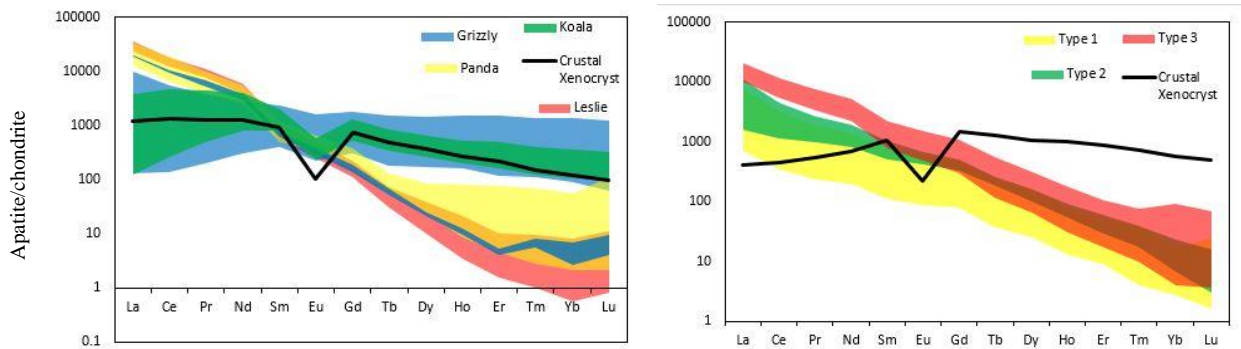
Figure 2: Chondrite normalised REE patterns of apatite from a) Ekati kimberlites, and b) Snap Lake. Crustal xenocrysts determined from textural relationships (xenolith inclusions).

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