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Chloride and carbonate immiscible liquids at the closure of the kimberlite magma evolution (Udachnaya-East kimberlite, Siberia)

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Abstract

The compositions of parental magmas forming kimberlitic rocks remain largely unknown because of masking effects of syn-eruptive contamination and degassing, and post-magmatic alteration. Among most affected elements are volatiles (H_2O and CO_2) and alkalies (Na and K). This study attempts to overcome the problems related to the alteration of kimberlites by detailed petrographic and chemical analyses of exceptionally fresh, and thus essentially anhydrous (<0.5 wt.% H_2O), kimberlite samples from the Udachnaya-East pipe (Daldyn–Alakit region, Siberia). The groundmass of these kimberlites contains abundant carbonate (calcite, shortite, zemkorite) and chloride (halite, sylvite) minerals, cementing olivine phenocrysts, and forming round segregations ("nodules"). The nodules, belonging to the chloride and chloride–carbonate types, show no evidence of thermometamorphic effects on the contacts with the host kimberlite. The chloride–carbonate nodules demonstrate liquid immiscibility textures that are remarkably similar to those observed in the olivine-hosted chloride–carbonate melt inclusions at ~600 °C. The similarity of oxygen and carbon isotope values of carbonates from the groundmass and nodules ($\delta^{18}O$ 12.5 to 13.9‰ VSMOW; $\delta^{13}C$ –3.7 to –2.7‰ VPDB) points to their common origin at similar temperatures. We argue for crystallisation of the chloride–carbonate nodules from residual kimberlite melts, pooled after exhaustion of the silicate melt component. The enrichment of the residual melt in alkali carbonate and chloride is partly reflected in the bulk groundmass compositions (10–11 wt.% CO_2, 2.3–3.2 wt.% Cl, 2.6–3.7 wt.% Na, and 1.6–2.0 wt.% K). We propose that this enrichment is inherited from the kimberlite parental magma, and it can be responsible for the kimberlite low liquidus temperatures, low viscosities, and rapid emplacement.

Keywords: Kimberlite; Immiscibility; Chloride; Carbonate; Melt inclusions; Carbon and oxygen isotopes

1. Introduction

Kimberlite magmas are in many aspects unusual compared to other terrestrial magmatic liquids. They are renowned for carrying diamonds, but the kimberlite-diamond genetic links are still elusive. Despite significant research efforts, there is still uncertainty about the

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true chemical identity of kimberlite parental melts and their derivates. Kimberlite magmas are often contaminated by large quantities of lithic fragments and crystals, unrelated to the evolution of the parental melt. In most cases kimberlites are severely modified by syn- and post-magmatic changes that have altered the original alkali and volatile element abundances. These problems are reflected in the definition of the kimberlite rock as "*both a contaminated and altered sample of its parent melt*" (Pasteris, 1984). Numerous other definitions of the kimberlite commonly reflect on ultramafic compositions and enrichment in volatiles (CO_2 and H_2O) (Skinner and Clement, 1979; Clement et al., 1984; Mitchell, 1986) which are supposedly inherited from parental magmas.

The ultramafic silicate compositions of kimberlites are ascribed to abundant olivine phenocrysts (olivine-II) in the groundmass, whereas significant CO_2 and H_2O abundances are attributed respectively to carbonate minerals (calcite and dolomite) and serpentine (+ other H_2O-bearing magnesian silicates). It is still debatable whether all measured H_2O in kimberlites had magmatic origin or was partly introduced post-emplacement (Sheppard and Dawson, 1975). On the other hand, shallow-level evolution of the volatile-rich kimberlite melt can be accompanied by the loss of volatiles (particularly CO_2). This is another factor complicating quantification of the parental melt composition if inferred from bulk kimberlite analyses.

In general, the broad compositional range of kimberlites is defined by two end-members, magnesian silicate (olivine and serpentine) and carbonatitic (calcite). Thus, the kimberlites worldwide form a trend between these two end-members, Mg-rich and Ca-rich respectively (Fig. 1). It is likely that several processes can account for this compositional array. For example, crystallisation of olivine and segregation of carbonatitic melt (Ca increase) is counter-balanced by olivine accumulation and removal of carbonatitic melt (Ca decrease). Whatever the reason for the build-up in Ca, a general consensus exists that the magmatic carbonatitic component is an integral part of all kimberlite rocks, and their parental magmas. What still remains to be understood is why an expected increase in concentrations of alkali elements (Na and K) during the evolution of the kimberlite magmas is not reflected in the compositions of common kimberlites (e.g., Na_2O is invariably <0.3 wt.%). Moreover, low abundances of these elements relative to the elements of similar incompatibility are not easily reconciled with expected geochemical characteristics of low-degree mantle melts, even if residual phlogopite is present in the source peridotite (le Roex et al., 2003).

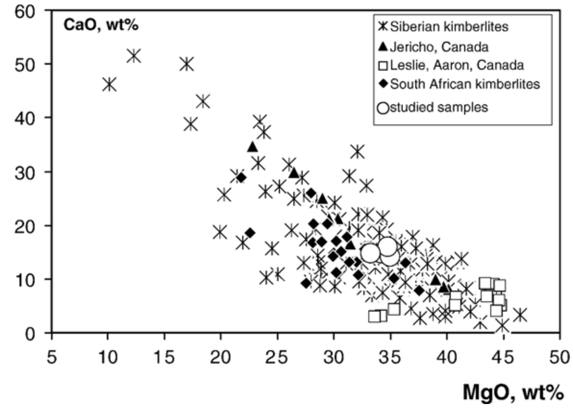

Fig. 1. MgO vs CaO compositional co-variations among Group I kimberlites from Siberia, South Africa and Canada (Price et al., 2000; Vasilenko et al., 2002; Bogatikov et al., 2004; Fedortchouk and Canil, 2004; Harris et al., 2004; Becker and le Roex, 2006). All compositions are recalculated to 100 wt.% on a volatile-free basis.

The idea of an alkali element loss and an H_2O gain in kimberlites during post-magmatic processes can be promoted based on the fact that all kimberlites studied to date are, to some extent, altered rocks. The alteration of the carbonate fraction towards essentially alkali-free calcitic compositions has been advocated since the discovery of modern alkali natrocarbonatite lavas from the Oldoinyo Lengai volcano and their altered counterparts (Dawson, 1962; Gittins and McKie, 1980; Hay, 1983; Deans and Roberts, 1984; Clarke and Roberts, 1986; Dawson et al., 1987; Dawson, 1989). Rapid degradation of alkali carbonates and dissolution of alkali chlorides in crustal environments can be responsible for depriving kimberlites (carbonatites) of their original sodium and potassium. But how do we learn about magmatic alkali abundances in kimberlites without having an "Oldoinyo Lengai" case among kimberlites?

This paper provides unequivocal evidence for the preservation of alkali carbonates and chlorides in the groundmass and olivine-hosted melt inclusions in at least some kimberlitic rocks. Our example of an unaltered kimberlite of the diamondiferous Udachnaya-East pipe in Siberia reveals the presence of significant quantities of non-silicate melt components in a common Group I kimberlite magma. We propose that an essentially non-silicate melt aggregated within the solidifying kimberlite groundmass and underwent carbonate–chloride unmixing at temperatures <600 °C.

2. Udachnaya-East kimberlite: location and samples

The Udachnaya diamondiferous kimberlite pipe is located in the Daldyn–Alakit region of the Siberian