The role of water in generation of group II kimberlite magmas: Constraints from multiple saturation experiments

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ABSTRACT

Multiple saturation experiments have been performed in a multicomponent system at 6.3 to 7.5 GPa and 1400–1670 °C using a split-sphere multi-anvil apparatus to constrain the conditions of kimberlite magma generation. The starting bulk compositions of samples corresponded to the average group II kimberlite (orangeite), with water contents varying from 5 to 9 wt% H₂O and the CO₂/(CO₂+H₂O) molar ratio from 0.37 to 0.24. The charges were placed inside graphite liners sealed in Pt capsules to avoid Fe loss. Oxygen fugacity (fO₂) during the experiment was buffered by the equilibrium between graphite and a hydrous carbonate-silicate melt about EMOG/D. As water in the starting kimberlite increased from 5 to 9 wt%, the temperature of its complete melting became ~100 °C lower (relative to 1670 °C), both in the 6.3 and 7.5 GPa runs. Orthopyroxene was stable just below the liquidus at all pressures and H₂O concentrations applied in the experiments. An olivine + garnet + orthopyroxene assemblage was present at ≤100 °C below the liquidus when H₂O was 5 wt%. At 7 and 9 wt% H₂O, the same assemblage appeared at 100–150 and >200 °C below the liquidus, respectively. In no experiment was clinopyroxene observed as a run product. Olivine, garnet, and orthopyroxene stable in the multiply saturated melt were compositionally similar to mantle peridotite minerals found as xenoliths in kimberlites worldwide. Thus we infer that generation of group II kimberlite magma may occur by partial melting of carbonated (metasomatized) garnet harzburgite at pressures from 6.3 to 7.5 GPa, temperatures about 1500–1600 °C, and no more than 5 wt% H₂O in the melt. Water, in the amounts required to produce this magma, may come from interaction of K-Ca-rich carbonatite melt, infiltrating from a deeper mantle source, with a peridotite protolith containing H₂O in nominally anhydrous minerals and, possibly, also in phlogopite.

Keywords: Experiment, mantle, kimberlite, magma, water, fluid

INTRODUCTION

Group II (micaceous) kimberlite is an ultrabasic rock rich in potassium and volatiles, with macrocrysts and phenocrysts of phlogopite in the groundmass (Smith et al. 1985; Mitchell 1986). Its geochemistry indicates an origin from lithospheric mantle source regions metasomatized by melts or fluids associated with ancient subduction events (Becker and Le Roex 2006). However, the specific conditions of magma generation, and especially the role of volatiles, remain a subject of discussions (Ulmer and Sweeney 2002; Brey et al. 2008, 2009; Foley et al. 2009; Kamenetsky et al. 2009; Girdulis et al. 2011; Sokol et al. 2013a, 2013b). According to experimental evidence, kimberlite magma can be produced by small-degree partial melting of carbonated peridotite in lower lithospheric or asthenospheric sources (Canil and Sarno 1990; Gudfinnsson and Presnall 2000; Ulmer and Sweeney 2002; Brey et al. 2008, 2009; Foley et al. 2009). Strongly fractionated REE patterns of kimberlites, with high LREE enrichment, imply partial melting in the presence of residual garnet (Mitchell 1986; Ringwood et al. 1992). Thus, olivine, garnet, and pyroxene should be present at or near the liquidus in kimberlite magmas in the P, T, F_O2, and fCO2 conditions in which they separated from their source lithology (Ringwood et al. 1992).

The pressures and temperatures at which magma becomes saturated in near-liquidus multiphase residue can be found experimentally by the so-called multiple saturation technique. It is applicable if (1) the starting material represents a primary magma composition; (2) equilibrium is achieved between the melt phase and the residue at a specific pressure and temperature (Ulmer and Sweeney 2002; Funk and Luth 2012).

Saturation of group II kimberlite melt with olivine, orthopyroxene, and garnet (garnet harzburgite residue) was studied (Ulmer and Sweeney 2002) at pressures from 4 to 10 GPa and at temperatures in a broad range. Note that the cited experiments at the pressures 6.0 and 7.5 GPa, the most important for group II kimberlite generation, were run at temperatures within 1480 and 1450 °C, respectively, and the liquidus was not encountered. The authors suggested two explanations of their results: either (1) the used kimberlite compositions did not represent the primary compositions being enriched in olivine, orthopyroxene, or garnet components by incorporation of harzburgitic xenoliths, or (2)