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Carbonatitic to silicic melt inclusions in lherzolite xenoliths from Lac de Gras, Slave Craton – Melt differentiation and mantle metasomatism

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Globules (1 to 4 mm), patches and veinlets of quenched silicate and carbonate melts occur in Cr-diopside in megacrystalline lherzolite xenoliths (1000ºC, 5GPa; Griffin et al. 1999) from the A154N kimberlite, Slave Craton, Canada. They belong to the suite of samples previously investigated by van Achterbergh et al. (2004). The clinopyroxene xenocrysts are intensively fractured and veined by the same material composing the globules and patches. They show a large range of textural and chemical variation (Figure 1) from carbonatite (C) to calcitic-silicate (CS) and calcite-bearing silicate (CbS). Calcite is the only carbonate and varies from 3 to 97% (modal).

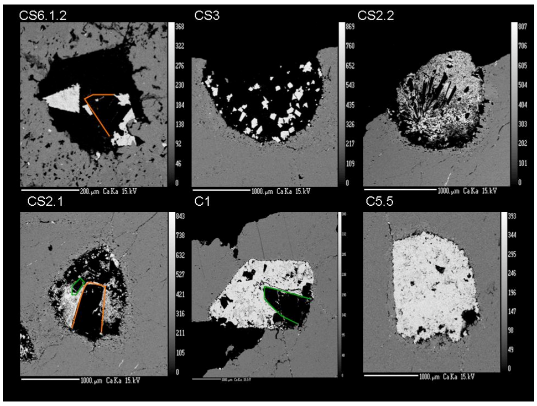

Figure 1 – SEM Ca images of calcite-silicate (CS) and carbonatite (C) globules. Black regions outside the globules in CS3, CS2.1 and C1 are the edge of the sections. Olivine occurs in CS2.1 (radial texture), CS2.1 and C1 (green outline). Phlogopite occurs in CS6.1.2 and CS2.1 (orange outline) and as an accessory phase in all other occurrences. Silicate matrix dominates CS6.1.2, CS3 and is unmixed in the upper part of CS2.1.

Major- and trace element contents of the phenocrysts and matrices in eighteen globules and the host clinopyroxene have been analysed using EMP and LA-ICPMS. The Cr-diopside is intensively metasomatised around the globules and veins. The globules contain phenocrysts of olivine ($fo_{89\text{-}92}$), phlogopite (low to high Al-K, probably interlayered phlogopite-chlorite), and calcite (Ca# >0.97) in matrices ranging in composition (EMP) from carbonatitic (calcitic) to Fe-Mg-silicic (1wt% Al_2O_3, 0.3wt% K_2O, 0.3wt% Na_2O). Phlogopite and calcite phenocrysts are accessory to major constituent phases and olivine abundance does not exceed 25%. Carbonatitic and silicic matrices are the dominant components of most globules, or may occur as segregated portions within single globules. Matrices with mixed compositions between carbonatitic and silicic end-members can have up to 18% CaO. Quenched textures include elongated olivine phenocrysts with radial texture (Figure 1) and segregated Fe-Mg-Si-phases within a carbonatitic matrix with ring, microlith and colliform microstructures. Sulphide and chromite are rare.

Calcite phenocrysts in carbonatitic and silicic globules have overall high REE (ΣREE = 1250 ppm), Ba (up to 3200ppm) and Sr (up to 5500 ppm) contents and flat chondrite-normalised (CN) REE patterns.. Calcite in the interstitial matrix ranges from compositions similar to calcite phenocrysts to lower REE contents, but comparable Ba and Sr, giving high Ba/La (CN) and a strong positive Sr anomaly. This compositional range is also found in carbonatite matrix where calcite phenocrysts are absent.

The silicic, Ca-silicic and carbonatitic matrices are enriched in LREE and have similar chondrite-normalised patterns, with some exceptions such as variable Ba/La and Sr/Nd ratios (Figure 2).

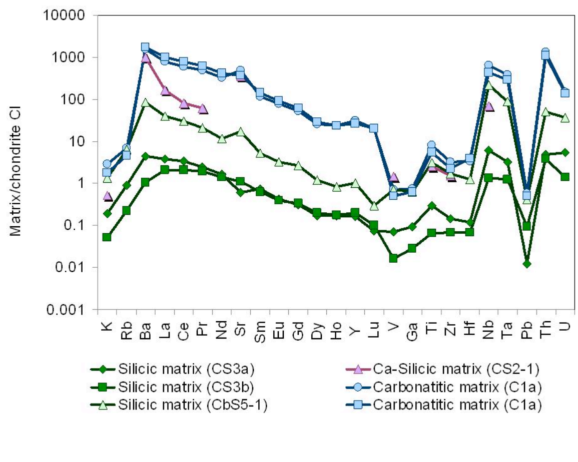

Figure 2 – Chondrite-normalised trace-element distribution of silicic, Ca-silicic and carbonatitic matrices.

All globules, patches and veinlets are surrounded by reaction zones in which the host diopside shows a marked increase in trace element contents and higher LREE/HREE, Nb/Ta and Th/Pb (Figure 3). The CN trace-element distribution of the metasomatised cpx around carbonatite and calcite-silicate globules is very similar and the highest enrichment is found in cpx rimming calcite-bearing silicate.

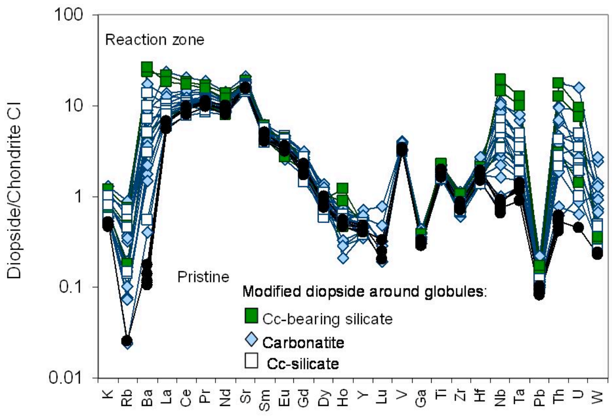

Figure 3 – Chondrite-normalised trace-element patterns of diopside rimming the globules compared to the pristine composition outside the reaction zone.

Carbonate-silicic melt inclusions described by van Achertberg et al. (2004) were interpreted as frozen melt inclusions with kimberlitic composition which were trapped by the host clinopyroxene shortly prior to the xenoliths incorporation in the ascending kimberlite. Similar quenched textures and unmixed silicic and carbonatitic matrices are likewise interpreted as disequilibrium textures.

The composition of the matrices and the bulk compositions of selected globules (calculated from modal composition) cover most of the range between phlogopite and calcite compositions in the ternary plot SiO_2-MgO-CaO (Figure 4) where carbonatitic (>97% calcite) and calcite-bearing silicate (<3% calcite) globules are end-members.

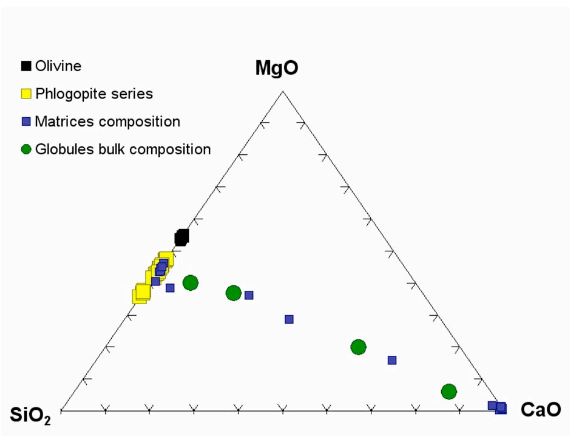

Figure 4 – SiO_2-MgO-CaO (Wt%) composition of the matrices, olivine, phlogopite series and bulk compositions of C1, CS3, CS6.2.1 and CS6.1.4).

Our results are similar to the composition of the Diavik and Jericho kimberlites in the ternary plot SiO_2-MgO-CaO (Figure 5). The Diavik kimberlite is a volcanoclastic phase (Graham et al. 1999) and coincides with the macrocrystic kimberlite from Jericho (Price et al. 2005). The Jericho aphanitic kimberlite, which is interpreted by the authors as closest composition to the parental kimberlite magma, lies along the compositional line defined by the globules. The saline to carbonatitic fluid inclusions (FI) in coated diamonds from Diavik cluster about this line.

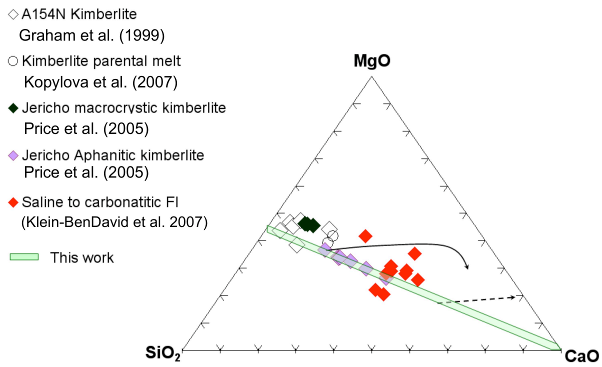

Figure 5 – Ternary plot SiO_2-MgO-CaO with composition of Diavik and Jericho kimberlites and fluid inclusions in Diavik coated diamonds. Also shown are kimberlitic to carbonatitic melts in equilibrium with carbonated peridotite (solid arrow; Dalton and Presnall 1998a, 1998b, Gudffinsson and Presnall 2005) and carbonated eclogite (dashed arrow; Brey and Yaxley 2004). In figure legend – put dot after "al", and fix Klein-BenDavid

The compositions of melts in equilibrium with metasomatised diopside around the globules has been calculated using partition coefficients between clinopyroxene and kimberlitic (Fujimaki et al. 1984 and Keshav et al. 2005) and carbonatitic melts (Adam and Green et al. 1992, Sweeney et al. 1995, Klemme et al. 1995, Blundy et al. 2000). The calculated fluids have overall similar compositions (Figure 6), but the influence of PT conditions and starting materials used in each experiment are yet to be discussed.

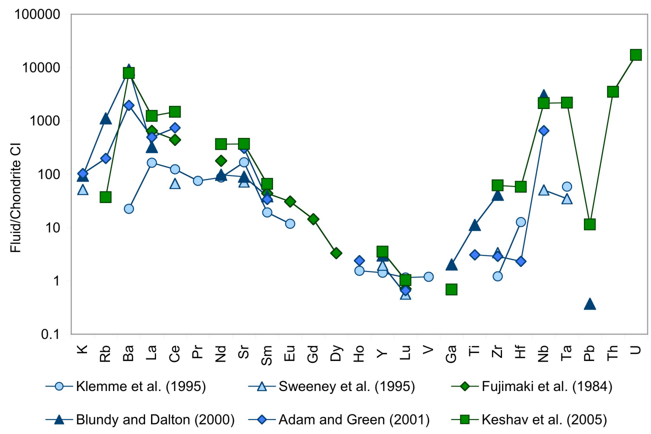

Figure 6 – Composition of the fluids (CN) in equilibrium with the metasomatised cpx using Kd(cpx/melt) from the literature (see text).

The trace element patterns of the Diavik and Jericho kimberlites have lower alkalies, LREE and Ba, relative to the HREE, than the calculated fluids (Figure 7).

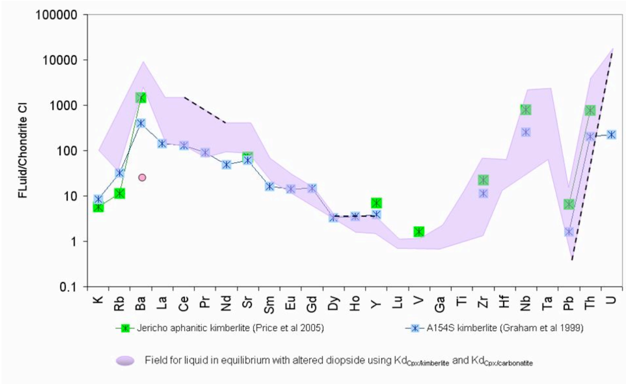

Figure 7 – Composition (CN) of Jericho and Diavik kimberlites compared to the range of fluids in equilibrium with the metasomatised diopside (sese text). Circle fluid using Kd(Ba) from Kempe et al.(1995). Dashed line – no Kd data.

Both the major element compositions of the globules and the metasomatic overprint in the host diopside suggest parental melts with kimberlitic to carbonatitic compositions, evolving fluids with fractionated compositions. Kimberlitic to carbonatitic melts in equilibrium with carbonated peridotite (Dalton and Presnall 1998a, 1998b; Gudffinsson and Presnall 2005) are produced experimentally with decreasing pressure (8 to 6 GPa) and temperature (at 6 GPa), as indicated by the solid arrow in Figure 5. Similar results are found for melts in equilibrium with carbonated eclogite (Brey and Yaxley 2004), but the compositions of the melts are more calcitic (dashed arrow, Figure 4).

The compositional range of the globules from carbonatitic to silicic was produced before the entrapment of the melt inclusions, possibly by fractionation of calcite, olivine, phlogopite and interaction with the host rock. Further fractionation of carbonates and silicates from evolved fluids would drive them to end-member compositions. Additionally, fluid immiscibility could contribute to separation of carbonatitic and silicic melts. Immiscibility of carbonatitic and silicic melts in equilibrium with carbonated eclogite (6 GPa; 1300ºC) has been observed in experiments by Hammouda (2003).

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