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CONSTRAINTS ON COMPOSITION OF POSSIBLE DIAMOND-BEARING LITHOSPHERE AS SAMPLED BY THE VICTOR KIMBERLITE

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The Jurassic Attawapiskat kimberlites, emplaced into the ~ 3 Ga North Caribou Superterrane of the central Superior craton, sampled diamond-bearing sub-continental lithospheric mantle (SCLM) subsequent to a major thermal event, the 1.1 Ga Midcontinent Rift on the southern craton margin (e.g. White, 1972; van Schmus and Hinze, 1985; Kong et al., 1999; Heaman and Kjarsgaard, 2000). Previous studies have shown that whereas the nearby Kyle Lake kimberlites (1.1 Ga) sampled SCLM containing abundant harzburgite, these are rare at the Attawapiskat kimberlites (~180 Ma) (e.g. Sage, 1996; Sage, 2000; Armstrong et al., 2004; Scully et al., 2004). This may be due to refertilisation of the SCLM by melts/fluids associated with the Midcontinent Rift.

We aim to assess the diamond-stable regions in the SCLM beneath Attawapiskat and any impact the Midcontinent Rift may have had on these diamond-bearing lithologies. We further aim to determine the different styles of metasomatism that occurred in the SCLM; as melt metasomatism has previously been shown to be detrimental to diamond preservation (e.g. McCammon et al., 2001), its possible occurrence may constrain whether pre-rift diamonds may have survived beneath this region.

Samples for this study include eclogite/pyroxenite xenoliths and mixed parageneses mineral concentrate from the Victor Mine at Attawapiskat. We analysed a suite of 30 xenoliths - 17 bimineralic eclogite xenoliths have omphacitic clinopyroxene and garnet with 6 - 18 wt% MgO. Thirteen pyroxenite xenoliths – 5 of which are orthopyroxene bearing - have diopsidic clinopyroxene and garnet with 15 - 21 wt% MgO.

Pressures and temperatures of last equilibration could be calculated iteratively for the 5 orthopyroxene-bearing samples, with T ranging between 730 ºC and 830 ºC (Ca-in-Opx; Brey et al., 1990) and P between 2.3 GPa and 3.4 GPa (Al exchange between Grt-Opx; Nickel and Green, 1985). The bimineralic eclogites and pyroxenites yield temperatures of last equilibration between 790 ºC and 990 ºC (calculated at 5 GPa; Krogh-Ravna, 2000). Based on Cr-diopside from heavy media concentrate, we employed the single crystal geothermobarometer of Nimis and Taylor (2000) to derive a Jurassic model geotherm equivalent to ~36 to 38 mW/ m^2 surface heat flow. Projecting the thermometric data for eclogites onto this palaeogeotherm places the samples in the graphite stability field.

Na_2O in garnet and K_2O in clinopyroxene in the majority of eclogite xenoliths are low (< 0.09 wt% and < 0.08 wt%, respectively), which is usually taken as an indication that such eclogites are not derived from high pressures in the diamond stability field (McCandless and Gurney, 1989). Only one of the 17 eclogite xenoliths has garnet with elevated Na contents (Na_2O = 0.1 wt%). However, five of the 13 pyroxenite xenoliths and 26% of the high Ca-eclogitic (G3) and low Ca-eclogitic/pyroxenitic (G4)

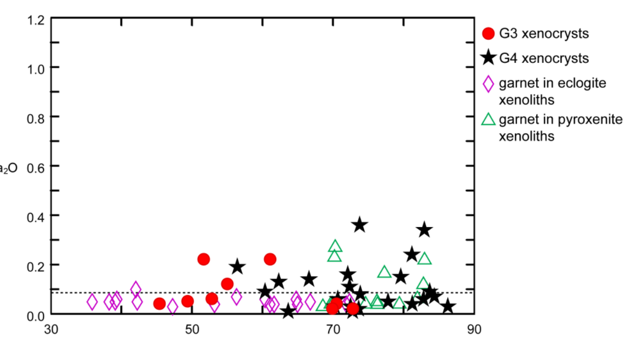

Figure 1. Na_2O versus $Mg\#_{Ca\text{-}corr}$ for G3 (high-Ca eclogitic) and G4 (low-Ca eclogitic to pyroxenitic) xenocrysts picked from mineral concentrate and garnet from eclogite and pyroxenite xenoliths. $Mg\#_{Ca\text{-}corr}$ = Mg# + 2 Ca (Ca as cations calculated on a basis of 24 oxygens), valid within the temperature and compositional limits outlined by Stachel et al. (2003). Na_2O content of 0.09 wt% is indicated with a dashed line (McCandless and Gurney, 1989).

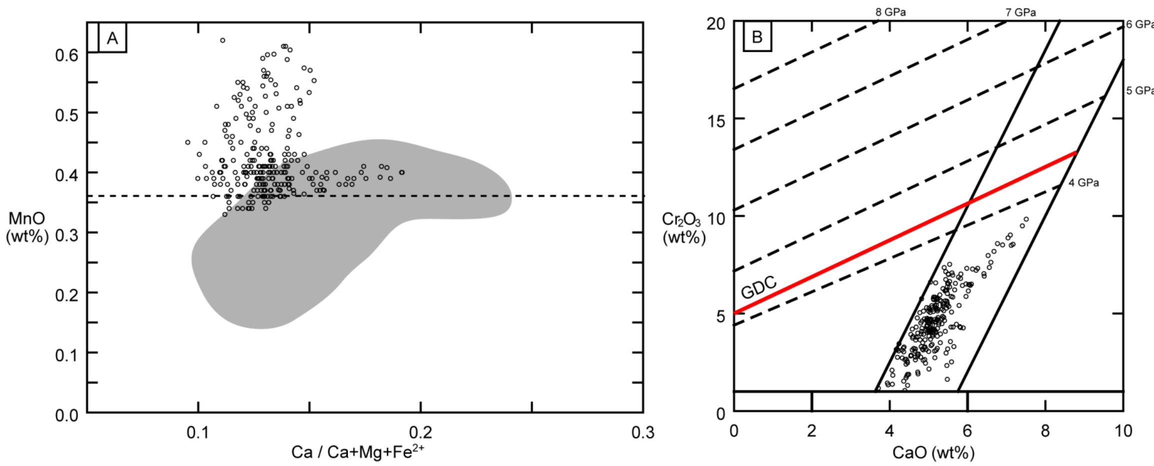

Figure 2. (a) MnO versus $Ca/Ca+Mg+Fe^{2+}$ for G9 from Victor. Based on Mn-in-garnet thermometry, only garnets with MnO < 0.36 wt% are expected to derive from depths within the diamond stability field (Grütter et al., 2004). Lherzolitic garnet inclusions in diamond (shaded field; database of Stachel and Harris, 2008) with MnO > 0.36 wt% - typically showing elevated grossular contents in part associated with low Mg-numbers - highlight the restriction of this approach to a "normal" compositional range. (b) Ca-Cr plot for G9 from Victor. Cr-in-garnet barometry (Grütter et al., 2006) indicates P < 4 GPa, i.e. derivation from depth outside the diamond stability field. However, Cr-in-garnet yields only minimum pressures if the assemblage is not spinel saturated (Grütter et al., 2006), which is commonly the case for garnet lherzolites. Average Ca intercept values are < 4.3, which indicates equilibration along a typical cratonic geotherm (Grütter et al., 2004).

garnets picked from mineral concentrate have garnets with Na_2O > 0.09 wt% (Figure 1). As bulk rock chemistry exerts a major control on Na_2O in garnet, many high Mg# garnets originating in the diamond stability field have low Na_2O (Grütter and Quadling, 1999). Therefore, it is possible that more pyroxenite and eclogite xenoliths are from the diamond stability field, even if it is not indicated in their Na_2O content. These results indicate that pyroxenite has the potential to be an important mantle source of diamonds in this region, as previously suggested for the AT56 kimberlite at Attawapiskat (Armstrong et al., 2004).

Lherzolite may also be a diamond source at Victor: Victor lherzolitic garnets have low Ca-intercept values (i.e., Cr-Ca relations falling close to the division between harzburgitic and lherzolitic garnets; Figure 2b) suggesting derivation from SCLM falling on a typical cratonic geotherm (Grütter et al., 2004), which is indicative of the presence of a diamond stable SCLM in the Jurassic. MnO contents in ~ 5% of lherzolitic garnets are < 0.36 wt% (Figure 2a), which is used as an approximate cutoff for diamond stable conditions by Grütter et al. (2004), based on Mn-in-garnet thermometery (Grütter et al., 1999). The thermometric expression of Grütter et al. (1999) does, however, ignore crystal chemical effects and, as a consequence, a number of lherzolitic garnet inclusions in diamond (by definition derived from the diamond stability field) with elevated grossular content and relatively low Mg-number fall above the 0.36 wt% MnO. Therefore, we are considering the proportion of 5% diamond stable lherzolitic garnets quoted above as a minimum value. The strongest indication for an elevated diamond potential of lherzolitic sources in the SCLM beneath Victor comes from a very high proportion of diamond stable Cr-diopside in concentrate: after applying the geochemical filters of Grütter (2009) to extract clinopyroxenes that are (1.) garnet lherzolite derived and (2.) compositionally suitable for application of the Nimis and Taylor (2000) geothermobarometer, 35 of the remaining 41 (i.e., 81%) Cr-diopside grains originate inside the diamond stability field.

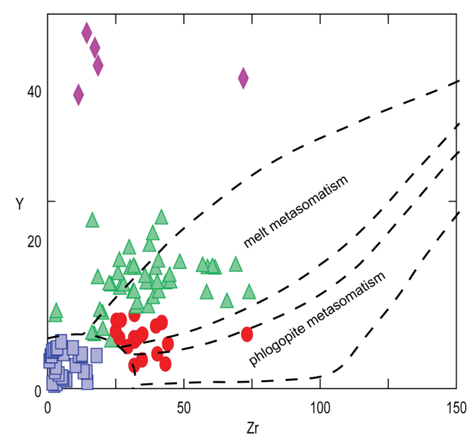

Figure 3. Y-Zr diagram from lherzolitic garnets documenting four different styles of metasomatism. Fields for melt and phlogopite (fluid) metasomatism from Griffin and Ryan (1995). Purple symbols – garnets re-enriched in Y but not in Zr, through an agent with unfractionated HREE/MREE. Green symbols – garnets re-enriched in Y and Zr through melt-dominated metasomatism. Red symbols – garnets re-enriched in Zr more than Y through fluid-dominated metasomatism. Blue symbols – "depleted" garnet.

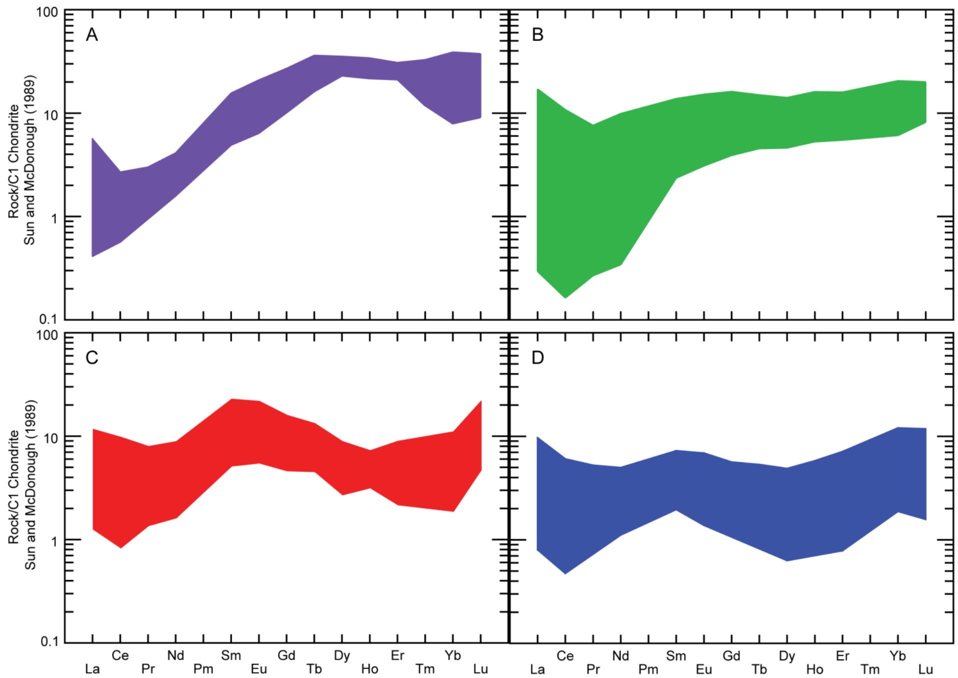

Figure 4. REE content for lherzolitic garnet normalised to C1Chondrite (Sun and McDonough, 1989). A. Garnet with positive slopes in $MREE_N$ to $HREE_N$ suggest metasomatism by a HREE-enriched agent/melt. B. garnet from lherzolitic sources that have been melt metasomatised, with relatively flat slopes from $MREE_N$ to $HREE_N$. C. Garnet from sources affected by fluid-dominated metasomatism show enrichment in the $LREE_N$ to $MREE_N$, resulting in complex sinusoidal pattern. D. Garnets that retain an originally depleted signature with a positive slope in the $HREE_N$ (reflecting melt extraction from a garnet bearing source) and some secondary LREE enrichment.

Lherzolitic garnets have both "depleted" and "enriched" REE compositions. Garnets that retain overall depleted signatures have complex sinusoidal REE_N (N=chondrite-normalised) patterns, similar to harzburgitic and lherzolitic garnets from Kyle Lake (Scully et al., 2004). Despite minor LREE enrichment, these garnets have low Y and Zr contents (< 5 ppm and 25 ppm, respectively), indicating that they were only affected by mild fluid-dominated metasomatism (Figure 3 and Figure 4D). With these REE characteristics and the modest levels of Y-Zr re-enrichment, the "depleted" lherzolitic garnets from Victor resemble garnets from diamondiferous lherzolite xenoliths from the Diavik Mine (Creighton et al., 2008).

Preservation of "depleted" garnet compositions below Victor suggests that the effect of the Midcontinent Rift may not have been that pervasive. "Enriched" garnets indicate both more intense fluid-dominated (increase in Zr content; LREE enrichment) and melt-dominated metasomatism (increase in both Y and Zr content; relatively flat $MREE_N$ to $HREE_N$) (Figure 3 and Figure 4B,C). Garnets that show enrichment in Y but not in Zr and a positive slope in the $MREE_N$ to $HREE_N$ are considered to have been enriched by an agent with fairly unfractionated HREE/MREE (Figure 3 and Figure 4A).

Our results indicate that whereas some diamond destruction may have occurred in relation to melt metasomatism in the SCLM below Attawapiskat, diamond-stable conditions were still prevalent in the lherzolitic SCLM during the Jurassic. The relationship of the melt metasomatic agent/s to the Midcontinent Rift will still be assessed. An additional source of diamonds below this area may be in the pyroxenitic and eclogitic SCLM.

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