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A silica enriched diamondiferous spinel harzburgite from Kaapvaal

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Cr-rich spinel (Cr_2O_3 60-70 wt %) forms a significant proportion of silicate inclusions found in diamonds worldwide. To date, however, the genesis of spinel peridotites assumed to be the host of these diamonds is poorly constrained. We report on the occurrence of two extremely well preserved chromite harzburgites from Kimberley, S.A., one diamondiferous and the second contains < 0.2 % modal sub calcic garnet.

Over the last four years a VU-DeBeers team has examined in excess of 25000 xenoliths from Kimberley S.A. One aim was to find spinel harzburgite xenoliths that may have been stored within the diamond stability field. In addition, samples needed to be little altered and lack evidence of the almost pervasive clinopyroxene metasomatism that characterizes Kimberley xenoliths (see recent review by Simon et al. 2007). Following these criteria 2 spinel harzburgite xenoliths were selected that contain no macroscopic clinopyroxene or disseminated phlogopite. One sample (AT 1000) is diamondiferous. This samples have been subjected to a combined detailed petrological major and trace element study (electron microprobe, XRF and laser ablation ICP-MS/SIMS) and the diamondiferous sample subjected to an integrated Os-Sr-Nd-Hf and C isotope study.

Petrographic Description

The diamondiferous harzburgite, AT 1000, is mildly foliated (opx aspect ratio of 1.25:1) is 30 x 25 x 15 cm and has diamonds exposed at two positions on the surface (> 1 ct exposed). No diamonds where recovered from the xenolith interior. The larger diamond occurrence (Fig 1b) comprises 3 intergrown octahedra with pronounced {111} stepped faces. Diamonds are transparent, two colourless while the third is pale brown. When fully liberated, the second diamond aggregate was found to be partially coated by MgO-rich glass and Mg-poor carbonate (Fig 2). The harzburgite comprises 69.5% olivine, 27% opx, and 3.5% chromite and no cpx or garnet. Three irregular 1-3 mm thick phlogopite dunite veins cut the sample. These veins and surrounding 1 cm were cut from the sample before preparation of whole rock powder and mineral separation.

The garnet bearing spinel harzburgite (AT 1163 gnt-sp-hz) 65 x 25 x 20 cm, comprises 75.7% olivine, 21.9% opx, 2.3 % chromite < 0.2 % garnet and no cpx. There

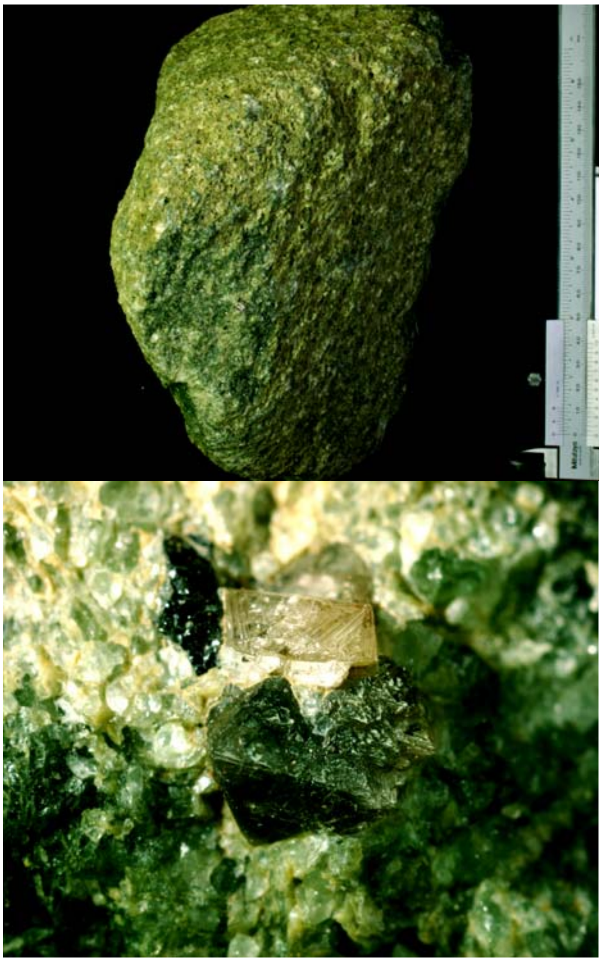

Fig. 1 a) Diamondiferous harzburgite xenolith, AT 1000 (max dimension 40 cm). b) Diamond aggregate (5 mm) of three octahedra with pronounced stepped growth faces. The diamonds contain < 20 µm inclusions that appear to be chromite (not yet extracted).

is a very weak fabric marked by elongated spinel. Spinels are up to 0.5 cm across, ol and opx up to 1.5 cm. The rare subhedral gnt crystals (~ 0.5 cm) are unaltered with no kelyphite rims.

Chemical Compositions

The major rock forming phases in both samples are highly magnesium, depleted in TiO_2 and Al_2O_3 and remarkably homogeneous; e.g., AT 1000 olivine Fo 95.44 ± 0.01 (1 SD); opx Mg# 96.04 ± 0.08, Al_2O_3

Fig.2 Diamond aggregate (4 mm) coated by Mg-poor calcite and Mg-rich glass.

Fig. 3 Part of garnet bearing spinel harzburgite xenolith AT 1163.

0.66 wt %; chromite Cr# 0.83, TiO_2 < 0.1 wt %. To date very few residual peridotite xenoliths have been reported with comparable Mg-rich compositions (see review by Pearson & Wittig 2008). Spinel compositions are within the range of diamond inclusions (Fig. 4). The garnet from AT 1163 is sub calcic with CaO and Cr_3O_3 of 0.7 and 6.5 respectively.

Despite the highly melt depleted nature and extremely high MgO content (50%) the diamondiferous sample has a low Mg/Si of 1.19. This composition is among the most markedly SiO_2 enriched residual peridotites yet recorded (Fig. 5). This sample therefore also has the potential to provide information about the Si-enrichment processes that have modified the Kaapvaal Craton and particularly establish if diamond formation is related to the Si-enrichment processes. In contrast, the gnt-sp-hz AT 1163 has significantly lower SiO_2 and Mg/Si ratio of 1.39, comparable to the most depleted oceanic lithosphere and forearc peridotites (see recent review by Simon et al. 2008). Both samples are extremely depleted in the magmaphile elements with similar FeO (Fig. 5), CaO and Al_2O_3, (CaO=0.09 and Al_2O_3=0.2).

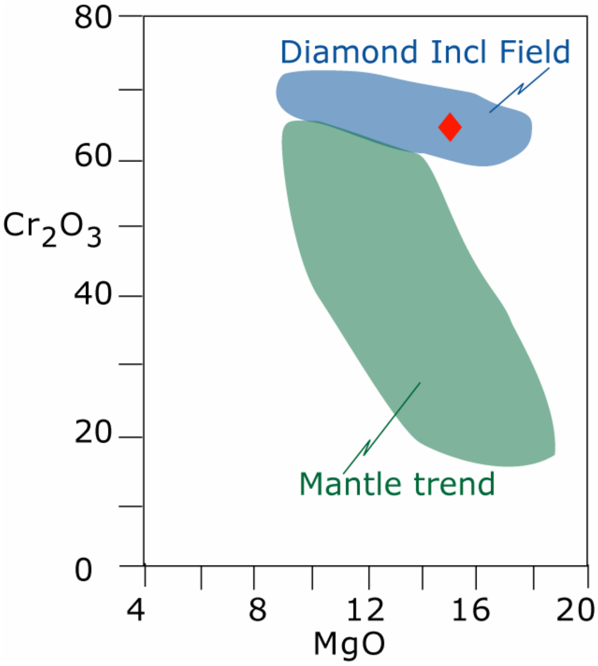

Fig. 4 MgO vs Cr_3O_3 for spinels with reference fields for diamond inclusions and peridotitic spinels. Red diamond, field of spinels from AT 1000.

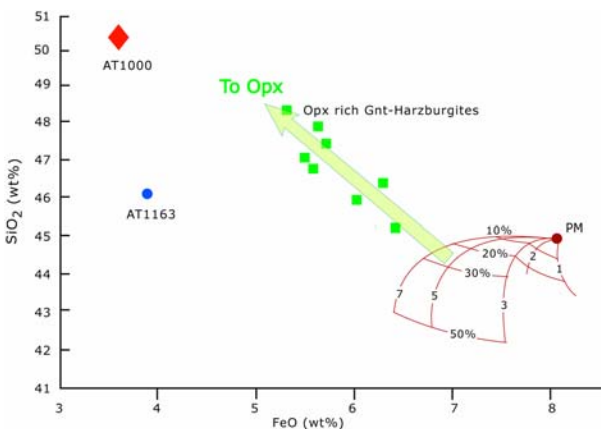

Fig. 5: Whole rock FeO vs SiO_2. Melting grid at 1 to 7 GPa after Walter 2003. Opx rich sub-calcic gnt-harzburgites from Kimberley for reference, Wijbrans et al. this volume.

SIMS carbon isotope analysis of fragments of one of the AT 1000 diamonds are in the range (-3.8 to -5.4 ‰). The carbonate in contact with the diamond was analysed by conventional stable isotope mass spectrometry and the glass by EMP. The carbonate has variable and ^{13}C depleted compositions (<-10‰). The Mg-rich glass (MgO >30%) has variable compositions and is locally devitrified with low alkali contents (Na_2O+K_2O < 2.5%). The glass is interpreted to represent host kimberlite frozen against the diamond during transport to the surface. Subsequent low temperature alteration leached alkali elements and led to carbonate deposition.

SIMS analysis of AT 1000 opx reveals a S-shaped LREE enriched pattern with a max at Nd_N (1.5) and a minimum at Er_N (0.02). The garnet and opx of AT 1163 have convex upwards patterns. Calculated WR REE patterns for both harzburgites are given in Fig. 6. The extremely low HREE (Yb_N ~ 0.02) content indicates formation by > 40% partial melting, the majority of which must have been in the absence of garnet, a conclusion compatible with the extremely high olivine Fo of > 95.5 (e.g., Bernstein et al. 2007). Further evidence for extreme melt depletion is provided by sub ppb PGE abundances in AT 1000 (e.g., Re 0.016 ppb), which suggests that melting proceeded to the stage where all sulphide and metal alloys where exhausted and hence that there were no residual phases into which PGE's could partition.

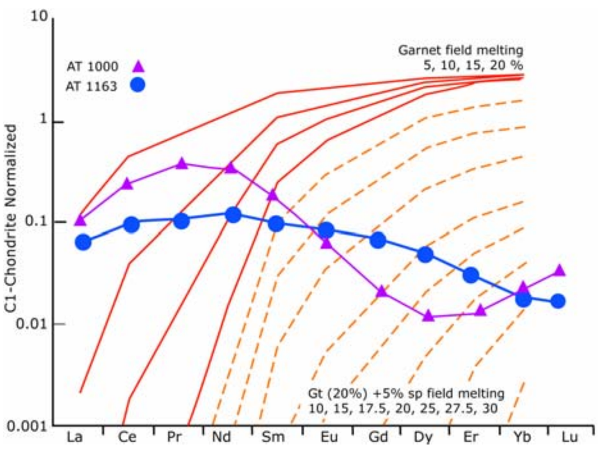

Figure 6. REE modeling of HREE depletion following Hellebrand et al. 2002 and Simons et al. 2007.

LREE enrichment characterises opx and gnt in the 2 sp-hrz. Opx in AT 1000 records low time integrated Nd and Hf isotope ratios that yield depleted mantle model ages of ~ 2.0 Ga for both Hf and Nd. The Re depletion age (T_{RD}) of this sample is 1.7 Ga. T_{RD} ages are minimum ages and assume extraction from a chondritic mantle. Recent Os isotope data suggests that formation of the Bushveld Complex and E-type diamonds from Venetia and Premier at 2.05 Ga involved a mantle source with radiogenic Os (Richardson & Shirey 2008). If such material was involved in the genesis of AT 1000, Re-Os model ages would be older, even more comparable to the 2.0 Ga Hf-Nd enrichment ages. An additional factor that may lead to the Os model age being slightly younger than Hf-Nd model ages, is that the highly depleted PGE content of AT 1000 makes the rock highly susceptible to kimberlite-rock interaction.

Relative Ti and Zr depletion in calculated WR compositions of both sp-hrz indicate that metasomatism led to relative high field strength element (HFSE) depletion, possibly by subduction-related fluids. High precision isotope dilution HFSE analyses are currently underway to substantiate this finding and constrain the tectonic environment of the metasomatism.

Conclusions

Spinel-(garnet) harzburgites form Kimberley have undergone extensive melt depletion (>40 %), predominantly in the spinel stability field. Such extreme melting probably indicates the presence of H_2O during melting. Subsequent silica and LREE enrichment of AT 1000 is inferred to occur in a subduction zone setting associated with tectonic transport to the garnet stability zone where metamorphic reactions between opx and spinel led to the formation of sub-calcic garnets (AT 1163). AT 1000 does not contain sufficient Ca to form garnet despite, transport to the diamond stability field.

The comparable Hf-Nd-Os model ages (~2.0 Ga) suggest that the major melting and SiO_2 and trace element enrichment events occurred in a short period of time (< 100 Ma), probably in a single tectono-magmatic event associated with the Bushveld province magmatism.

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