9th International Kimberlite Conference Extended Abstract No. 9IKC-A-00195, 2008

Extremely depleted lithospheric mantle and diamonds beneath the southern Zimbabwe Craton

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Introduction and geological setting

Mantle xenoliths and diamonds from the 538 Ma Murowa and Sese kimberlites in Zimbabwe (Smith et al., 2004) have been used to characterise the nature of the lithosphere beneath the southern Zimbabwe Craton. These kimberlites lie near the southern edge of the Craton, intruding 2.6 Ga granite batholiths emplaced into the ~ 3.0 Ga Buhwa Greenstone Belt 10-20 km north of the boundary of the Northern Marginal Zone of the late Archean Limpopo Mobile Belt (Fig. 1). The greenstones are believed to rest on non-outcropping ~3.5 Ga gneissose Tokwe Segment basement.

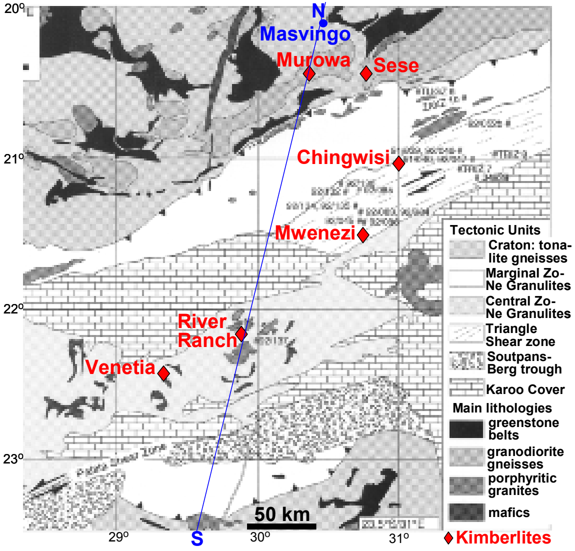

Fig. 1. Geological setting of the Murowa and Sese kimberlites (modified from Kamber et al., 2004).

Mantle xenoliths

Mantle xenoliths identified are entirely peridotitic with dunite predominating over harzburgite and lherzolite. Textures are coarse granular to porphyroclastic. Some dunites are megacrystic, formed of single crystals of olivine, containing occasional subcalcic chrome pyrope inclusions. Accessory aluminous Cr-spinel is present in vermiform or cuspate shapes suggestive of re-equilibration (Fig. 2).

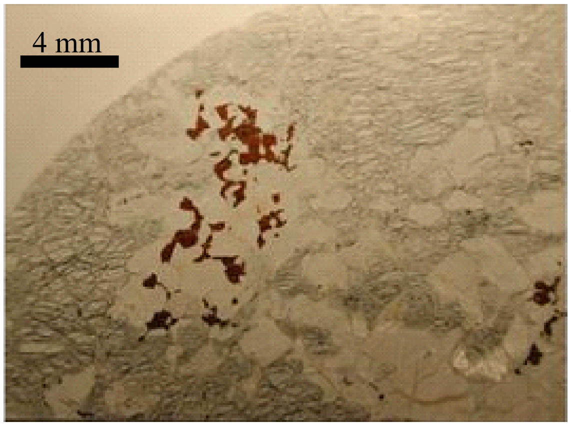

Fig. 2. Sample GP14 (ordinary light): Porphyroclastic, coarse granular, spinel lherzolite from Murowa K1. Pale clinopyroxene and orthopyroxene occur patchily in clots, associated with intergranular, vermiform, chrome spinel (Cr_2O_3~40%).

Olivines in the dunites and harzburgites have mg values of 0.90-0.95, spanning the average for Kaapvaal craton peridotites (Fig. 3).

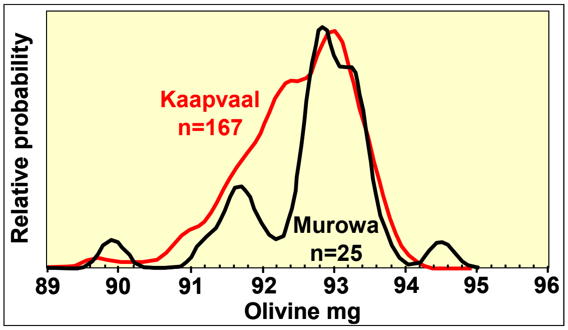

Fig. 3. Olivine mg for Murowa/Sese peridotites

Diamonds

The diamonds are of octahedral, transitional and dodecahedral shape, in order of abundance. They are mainly white, pale brown and pale yellow in colour. Most of the crystals have simple octahedral internal growth zonation and blue photoluminescence colour. They contain moderate amounts of nitrogen (60-500 ppm) with medium degree of aggregation (40-60% of 1aB type).

Diamond inclusions are almost entirely peridotitic, with high Cr magnesio-chromite and olivine (fo 0.91-0.94) predominating over enstatite (mg 0.93-0.96), subcalcic chrome pyrope, Ni-rich sulphide and yimengite. Eclogitic omphacites were recorded in two Murowa diamonds.

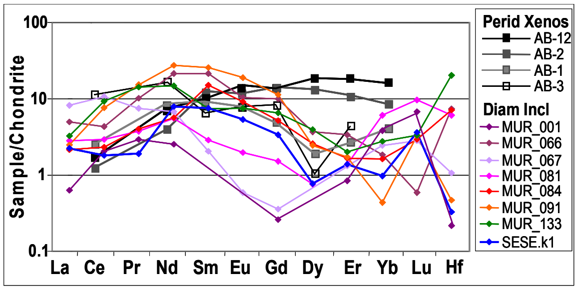

Fig. 4. Chondrite-normalised REE patterns for garnets from Murowa peridotite xenoliths and Murowa and Sese diamond inclusions.

All of the diamond inclusions and two of the peridotite xenoliths (AB1 and AB3) have pyropes with sinusoidal REE patterns depleted in HREE that are typically associated with dunites and harzburgites world wide (Fig. 4). This includes the Ca-rich pyrope from diamond Murowa_133. Two dunite xenoliths (AB12 and AB2) have pyrope with lherzolitic REE patterns, perhaps due to re-fertilisation.

Kimberlite Concentrate Minerals

Concentrate minerals from the kimberlite are dominated by magnesio-chromite similar in chemistry to diamond inclusion chromites (Fig. 5), and by chrome pyrope (30% lherzolitic “G9”, 70% subcalcic harzburgitic “G10”) (Fig. 6).

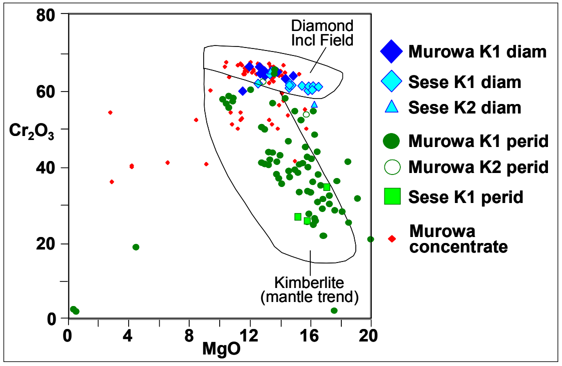

Fig. 5. MgO-Cr2O3 plot for chromites from Murowa & Sese peridotites, diamond inclusions & concentrates.

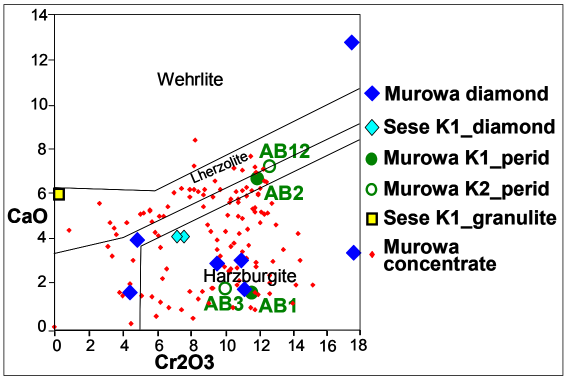

Fig. 7. Cr2O3-CaO plot for garnets from Murowa & Sese peridotites, diamond inclusions and concentrates.

Peridotite xenolith chemistry

As expected from their highly depleted mineral chemistry, the Murowa peridotites have bulk compositions that are depleted in magmaphile elements. Their compositions are amongst the most depleted of any cratonic peridotites, with Ca and Al contents matched only by the most depleted North Atlantic Craton peridotites (Wittig et al., this volume). Mg/Si ratios are very high, in keeping with the olivine-rich, orthopyroxene-poor nature of the Murowa peridotites and as such this suite is considerably different from typical low Mg/Si peridotites that characterise the Kaapvaal cratonic lithosphere to the South.

The overall impression is therefore of an exceptionally depleted lithospheric mantle beneath the southern Zimbabwe Craton.

Thermobarometry

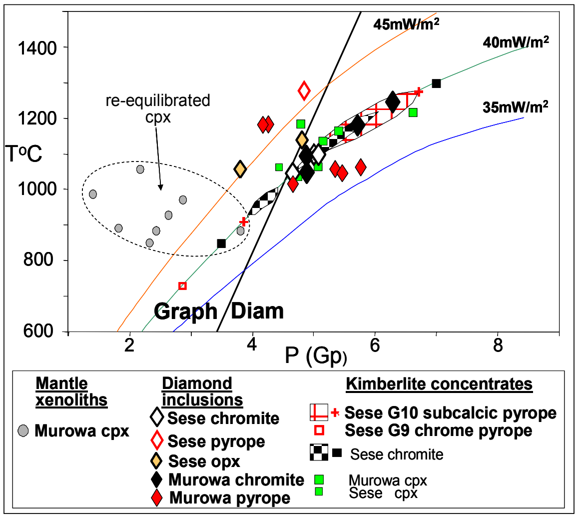

Fig. 8. Thermobarometry/geotherm plot for Murowa/Sese peridotites and diamond inclusions

Pyroxene, garnet and spinel thermobarometry suggests an ambient 40mWm^{-2} geotherm, with lherzolites coming from shallower depths than dunite-harzburgite assemblages which extend down to 210 km.

Xenolith pyroxenes re-equilibrated at low P during a metasomatic alteration event, probably during kimberlite entrainment. The diamond inclusions typically fall within the temperature range 1030-1250°C, with median values for garnet and chromite of ~1100°C. Diamonds seem to be common at top of the mantle section within the diamond stability field rather than towards the lithosphere base.

Dating of peridotites and diamonds

Whole rock peridotite Re-Os isotope analyses give initial γOs values of between -8.5 and -13, similar also to Kaapvaal Craton peridotites. Typical minimum TRD ages, of 2.7 to 2.8 Ga. are slightly younger in age than the basement greenstone formation but similar to the prominent mode in Re-depletion ages seen in the Kaapvaal craton. In contrast, the average Re-Os model age is 3.2 Ga.

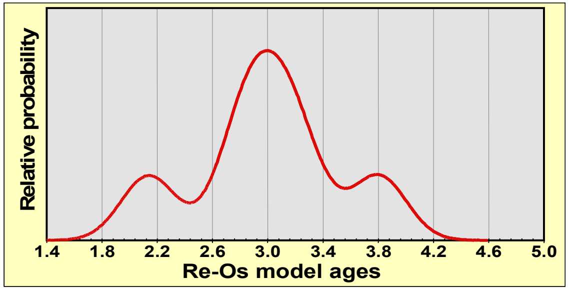

Fig. 9. Re-Os model ages for Murowa peridotite xenoliths

Whole rock Os data gathered so far suggests a model whereby thick lithospheric mantle was stabilised during the early stages of crustal development by shallow peridotite melting required for formation of residues with sufficiently high Cr/Al to stabilise chromite which then transforms to low Ca, high Cr garnet (e.g., Canil, 1992; Stachel et al., 1998). The shallow melting environment is strongly supported by very low whole-rock Yb concentrations and high Lun/Ybn ratios e.g. Wittig et al. (in revision).

A high Ni, high Os (6.5 ppm Os) sulphide inclusion in diamond of probable peridotitic paragenesis has an initial γOs value (at 533Ma) of -16.1, considerably less radiogenic than the bulk rock peridotites. This sulphide yields a TRD model age of 3.3 Ga and a Re-Os age of 3.5 Ga, confirming the meso-Archean age for the lithosphere in this region suggested by the Re-Os model ages for the whole rocks. With only a single sample, we cannot accurately estimate the range of diamond formation ages, but the single model age is consistent with the meso-Archean lithosphere formation age indicated by the whole rock data. The moderate N aggregation of the diamonds at temperatures of ~1100°C requires a long mantle residence time, supporting an Archean age of diamond formation.

Comparison with the lithospheric mantle beneath the Limpopo Mobile Belt

Literature review shows that mantle xenoliths, diamonds and concentrate macrocrysts from the Venetia, River Ranch, Mwenezi and Chingwise pipes which intrude the Limpopo Mobile Belt also show strongly depleted peridotitic mantle signatures. Seismic velocity imagery was interpreted by James et al. (2001) to indicate the presence of a deep lithospheric mantle keel beneath the Limpopo Mobile Belt today. The Mobile Belt seems therefore to be a product of thin skin crustal tectonics with the underlying lithospheric mantle linked to that of the southern Zimbabwe Craton and unaffected by these overlying crustal events. We interpret the highly depleted dunite-harzburgite assemblage as a product of shallow melting followed by subduction and accretion beneath the Zimbabwean cratonic crust of the Archean Tokwe Block.

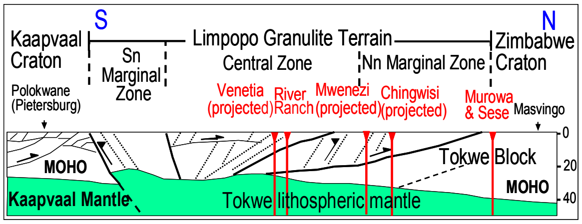

Fig. 10 Illustrative cross section from Limpopo Mobile Belt to southern Zimbabwe Craton (modified from Roering et al., 1992).

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