Mesoarchean to Mesoproterozoic Re-Os ages for sulfide inclusions in Orapa diamonds and implications for Kaapvaal-Zimbabwe craton development

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Rationale

Sulfide inclusions found in single macro-diamonds from the Orapa kimberlite have been studied to better understand the age spectrum of eclogitic diamond growth in southern Africa and its relationship to craton evolution. Detailed information at the western side of the Kaapvaal-Zimbabwe system and particularly that which might pertain to the subcontinental lithospheric mantle (SCLM) of the Zimbabwe craton is scarce.

Geologic setting and background

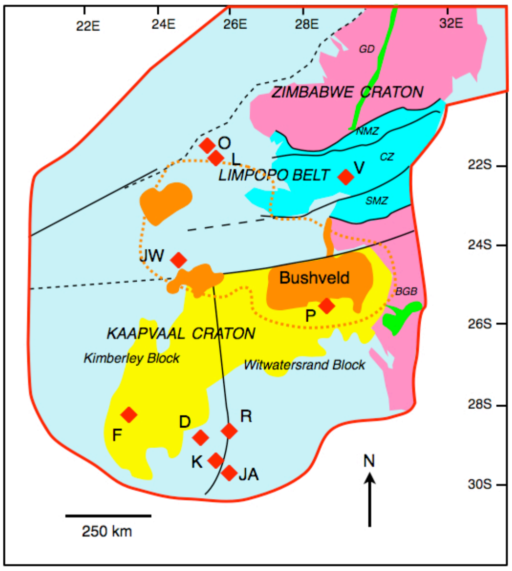

Fig. 1 Sketch map of the Kaapvaal-Zimbabwe cratons. O=Orapa, L=Letlhakane, V=Venetia, P=Premier, F=Finsch, D=DeBeers Pool (Kimberley), R=Roberts Victor, K=Koffiefontein, and JA=Jagersfontein. Bushveld-Malopo Farms intrusions in brown. Seismically slow lithospheric mantle at 150 km outlined by brown dashed line.

Orapa, is a 93 Ma old, Group I kimberlite that is known for its eruptive emplacement features, its eclogitic and relatively peridotite-poor xenolith suites, and its prodigious diamond production. It is situated in the Magondi metamorphic belt, west of the Zimbabwe craton margin in Botswana and in crust proximal to a region of seismically slow lithospheric mantle identified by the Kaapvaal Lithosphere Project (e.g. James and Fouch, 2002; Fig.1). However, due to limited outcrop, its relationship to the Limpopo belt is not evident. Compared to other diamond mines, Orapa inclusion-bearing diamonds are not rare and have been the object of much previous study. The studies most relevant to the present investigation have revealed a diamond population with a high proportion of isotopically light C and heavy N (Cartigny et al., 1999), a Neoproterozoic (990 Ma) eclogitic silicate inclusion population inherited from an Neoarchean protolith (ε_{Nd990}=-5, T_{DM}=>2.5 Ga; Richardson et al., 1990), and sulfide inclusions with anomalous mass dependent and independent sulfur isotopic compositions (Farquhar et al., 2002; Rudnick et al., 1993).

Results

Sulfides in this study were obtained from fracture-free diamonds, show syngenetic morphologies, and range in size from 50 to 300 microns in longest dimension. Backscattered electron imaging and energy dispersive X-ray analysis with the scanning electron microscope reveal pyrrhotite-chalcopyrite-pentlandite assemblages at the sulfide-diamond interface with more homogeneous, lower Ni and Cu pyrrhotite in the interior of grains. Such textures are typical and require complete grain bulk analysis to get accurate isotopic data (e.g. Richardson et al., 2001). The low range in Ni content, from less than 1 wt % to 15.5 wt % and the low Os content (9 to 138 ppb) both support only an eclogitic paragenesis for the sulphide inclusions. Re contents of the inclusions vary from 45 to 637 ppb, $^{187}Re/^{188}Os$ from 3 to 562, and $^{187}Os/^{188}Os$ from 0.191

to 8.21. Stable isotopic compositions obtained by SIMS on polished plates of the diamonds hosting the sulfides, relative to typical mantle values, are slightly lighter for carbon ($\delta^{13}C$ = -13 to -6) and similar to slightly heavier for nitrogen ($\delta^{15}N$ = -6 to +4) with N contents ranging from 125 to 1400 ppm. The more extreme carbon and nitrogen isotopic compositions that characterize the eclogitic diamond paragenesis (Cartigny et al., 1999) are rare in the diamond suite under investigation.

Discussion

The Re-Os isotopic ages of the Orapa sulfides when combined with previously published data on similar eclogitic sulfides from Jwaneng (Richardson et al.,

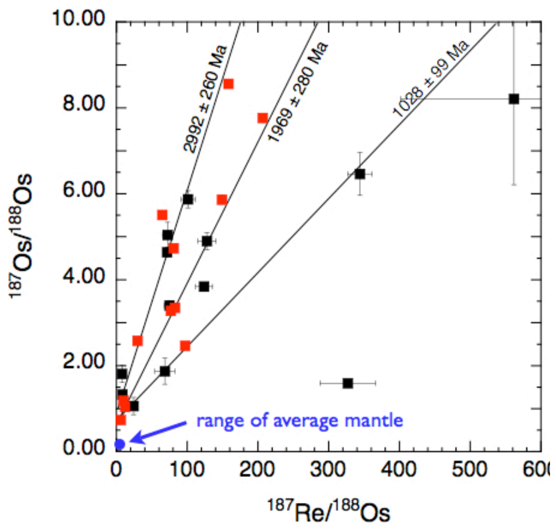

Fig. 2 Re-Os isochron diagram for eclogitic sulfide inclusions in Orapa (black squares) and Jwaneng (red squares) diamonds. Isotopic composition of typical mantle shown by blue circle.

2004), fall into three distinct age groups: 2992± 260 Ma, 1969±280 Ma and 1028±99 Ma (Fig. 2). The diamond population for both suites is roughly equally divided between the three age groups. The Mesoarchean age agrees with Re depletion model ages on peridotites from the Letlhakane kimberlite, some 40 km away (Carlson et al., 1999) and other suites of eclogitic sulfide inclusions from the Kaapvaal craton (e.g. Kimberley; Richardson et al., 2001). This age represents the time of SCLM stabilization shortly after amalgamation of the Witwatersrand and Kimberley blocks of the Kaapvaal craton (Shirey et al., 2001; Shirey et al., 2004). The 2 Ga age group gives the same age as sulfide inclusions from Venetia (Richardson and Shirey, 2008) and silicate inclusions from Premier (Richardson et al., 1990). This age could represent Bushveld magmatism (as at Venetia and Premier) but is more likely a product of crustal accretion (Jacobs et al., 2008) and metamorphism (Singletary et al., 2003) on the northwest side of the Kaapvaal-Zimbabwe craton from 2000-1850 Ma. The 1 Ga age is identical to the previous Sm-Nd isochron age obtained on eclogitic garnet and clinopyroxene inclusions in Orapa diamonds (Richardson et al., 1990) and matches the timing of the youngest metamorphism evident in crustal rocks in the Magondi Belt (Singletary et al., 2003).

The similarity between Orapa and Jwaneng sulfide inclusion data is striking. Not only do both 2.9 and 2.0 Ga age populations make up the suites but eclogitic protoliths with quite radiogenic initial $^{187}Os/^{188}Os$ of >0.5 are involved in diamond petrogenesis. The age range sampled by diamond growth is greater and the Os isotopic compositions are higher than other eclogitic sulfide inclusion suites more to the center of the craton such as Kimberley (Richardson et al., 2001) or Venetia (Richardson and Shirey, 2008). This is likely a consequence of nearly 2 billion years of marginal tectonics on the western side of the Kaapvaal-Zimbabwe cratons (Jacobs et al., 2008).

The Mesoarchean age of the SCLM beneath Orapa is older than the Neoarchean docking of the Zimbabwe craton on the northern edge of the Kaapvaal craton. Paleoarchean ages such as those suggested for the SCLM of the Zimbabwe craton by chromite deposits (Naegler et al., 1997) on the western side of the Great Dyke are absent in the Orapa suite. There is a similarity in Mesoarchean Re-Os age between the Orapa sulfide inclusions and sulfide inclusions (Kimberley, Jwaneng, Koffiefontein) and peridotite Os model ages (Carlson et al., 1999) found in the Kimberley Block of the Kaapvaal craton some 250 km to the south, across the westward extension of the Limpopo Belt and the Thabazimbe-Murchison Lineament. These features support the idea that the SCLM beneath Orapa may be a fragment related to the northern reaches of the Kaapvaal craton.

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