Garnet xenocryst chemistries in a traverse from Eendekuil to Kimberley over the south-western margin of the Kaapvaal craton

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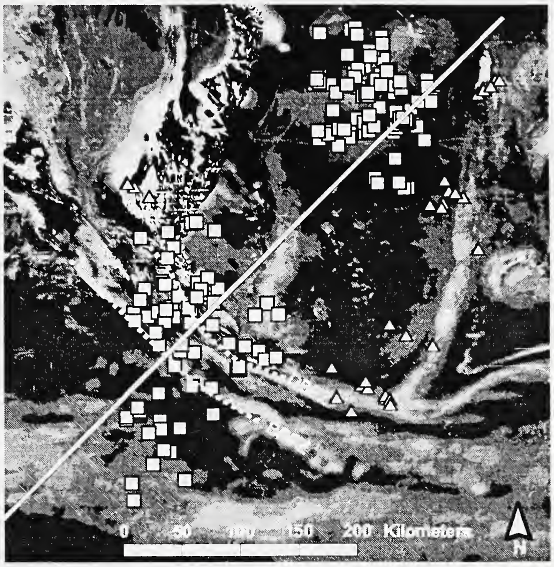

Fig. 1: Grey-scale magnetic image of the SW Kaapvaal craton and surrounding Namaqua domain. Squares denote positions for kimberlites for which garnet xenocryst data were projected onto the indicated traverse line. Other known kimberlites marked in triangles. BBFZ and DBFZ highlighted in dashed lines.

Some two hundred Jurassic-Cretaceous Group-1, Group-2 and transitional kimberlites occur in a ~ 140 km wide swath that trends north-eastward from the off-craton Eendekuil kimberlite across the south-western margin of the Kaapvaal craton to Kimberley (Fig. 1, see also Skinner et al., 1991). Three chronologically distinct crustal domains appear (at surface) along the ~ 580 km long traverse: the ~1.6-1.1 Ga central zone of the Namaqualand Metamorphic Complex occurs to the south-west of the Brakbos fault zone (BBFZ); the 3.2-2.9 Ga Kaapvaal craton occurs to the north-east of the Doornberg fault zone (DBFZ) and the 3.0-2.6 Ga Marydale domain occupies a ~ 40 km wide craton-margin buffer zone between the BBFZ and DBFZ (Fig. 1; Tankard et al., 1982). Crustal shortening at ~ 1.75 Ga and ~ 1.2 Ga, and ~ 1.05 Ga tectonic welding involving dextral transpression and > 200 km of dextral shear along the south-western Kaapvaal/Namaqua juncture, very likely left the BBFZ and DBFZ as deeply penetrating near-vertical structures (Stowe, 1983). This suggests that kimberlites straddling the BBFZ and DBFZ intrude three distinct crustal domains and may have sampled entirely different lithospheric mantles. In this contribution we utilise the chemistries of garnet xenocryst populations to examine the nature of the lithospheric mantle(s) that underlie the three crustal domains.

Our initial approach involved summarising garnet xenocryst compositions per intrusion according to the a simplified version of the garnet cluster group scheme of Danchin and Wyatt (1979), as well as the classifications of Gurney et al. (1993). The summaries thus obtained are available from the senior author on request; two of the significant features are outlined as follows:

- G10 subcalcic garnets are effectively absent from the sub-Namaqua lithosphere, increase in abundance below the Marydale domain and are reasonably common in the mantle below the Kaapvaal craton, particulary at Kimberley (Fig. 2). If G10 garnets are necessarily linked to the presence of diamonds, then the rules of Clifford (1966) imply that Archaean lithospheric mantle extends from Kimberley to below the Marydale domain and that the BBFZ forms a sharp, near-vertical craton boundary from surface to depths of ~ 120 km. The Markt kimberlite is situated just on the cratonic side of the BBFZ and is expected to be rooted in Archaean lithosphere.
- Eclogite is rarely sampled by kimberlites in the Kimberley area; craton-bound Group-2 kimberlites show a similar low incidence of eclogitic garnets (Fig. 3). Within the craton-margin environment eclogitic garnet xenocrysts occur in abundance, mostly in Group-1 kimberlites, on both sides of the BBFZ and DBFZ. These xenocrysts have distinctive iron-rich compositions that can be traced to eclogite and two-pyroxene/garnet granulite xenoliths of "lower crustal" provenance (Grütter and Robey, 1988; Pearson et al., 1995). Their paucity in Group-2 kimberlites indicates mantle sampling characteristics for these kimberlites that are substantially different from those of spatially associated Group-1 kimberlites.

The garnet xenocryst compositions were additionally subjected to geochemical and petrological calculations and results summarised per intrusion; some findings from these studies are as follows:

- The average chrome content of peridotitic garnet populations increases north-eastward from 3.2 to 4.4 to 4.8 wt% (± 0.9) below the three crustal domains in the traverse (Fig. 4). A marked difference in average Cr_2O_3 content clearly delineates the edge of the craton at the BBFZ. The maximum Cr_2O_3 in garnet increases north-eastward along the traverse, indicating that the depleted lithosphere thickens towards Kimberley (Nickel, 1989). The parallel increase in %G10 garnets (Fig. 2) suggests that geochemical depletion may impart stability to the thickened cratonic lithosphere via buoyancy forces.
- The average MnO content of low-titanium peridotitic garnet populations decreases slightly north-eastward along the traverse (Fig. 5). This implies that on-craton kimberlites are, on average, sampling common peridotite at higher temperatures, and by implication at higher pressures, than off-craton kimberlites. The highest temperature sampling occurs (at the lowest MnO contents) in the Kimberley area, but the average and inter-quartile ranges for MnO shown in Fig. 5 suggest considerable variation in the depth and depth extent of mantle sampling by different kimberlites.
- We have empirically calibrated MnO in peridotitic garnet as a single-grain geothermometer. The MnO thermometer allows the forsterite content of olivine in equilibrium with garnet to be calculated along the traverse (by inverting O'Neill and Wood, 1979). Equilibrium forsterite compositions were computed for low-titanium peridotitic garnets, normalised to a lherzolitic standard state at 950°C on a model 40 mW/m^2 geotherm, and averaged per intrusion. Fig. 6 shows that off-craton olivines are, on average, less magnesian (Fo91.9 ± 0.5) than on-craton olivines (Fo92.3 ± 0.5). These results are consistent with gross trends in olivine compositions for off- and on-craton peridotite xenoliths (Boyd, 1989). However, in finer detail our data show that about one-fifth of the kimberlites in the Kimberley area have sampled relatively fertile mantle characterised by Fo90.2 ± 0.9, reflecting smaller scale mantle heterogeneities.

The data presented here show that the bulk chemistry of average sub-Kaapvaal lithosphere is more depleted in terms of CaO (Fig. 2), Cr2O3 (Fig. 4) and Mg/[Mg+Fe] (Fig. 6) than that of the sub-Namaqua lithosphere. The division between these lithospheres occurs along the BBFZ which represents a dextral transform boundary established between Archaean and Mid-Proterozoic upper crustal domains at ~ 1.05 Ga. In addition to this prominent vertical divide, the Kaapvaal border region contains a presumably sub-horizontal stratification that is formed by eclogitic and pyroxenitic lithologies within the uppermost mantle and lower crust on either side of the BBFZ (Fig. 3). It is hoped that current geophysical studies within the area will contribute to the resolution of these sub-vertical and sub-horizontal mantle structures (de Wit and Gurney, 1997).

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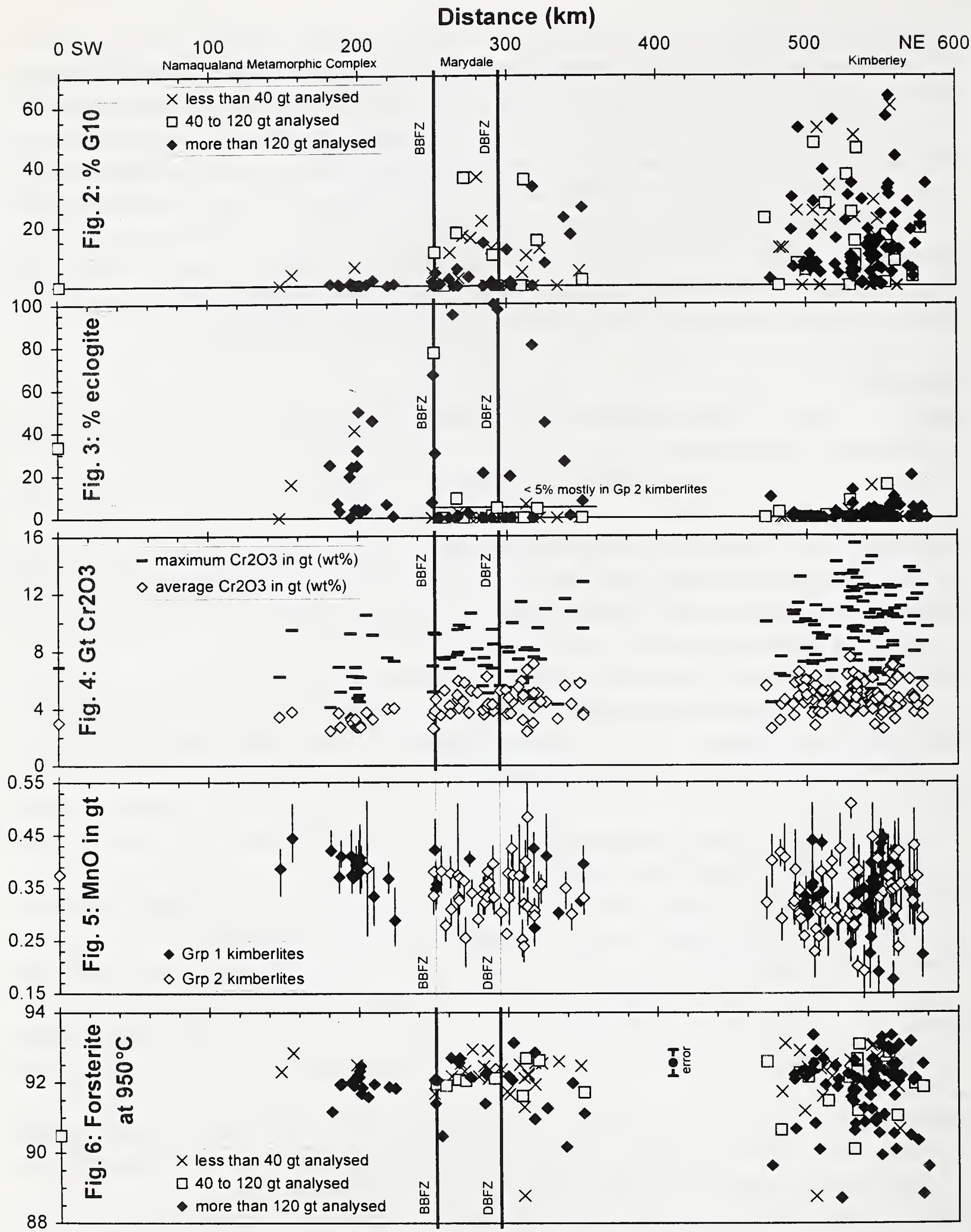
Distance (km)
0 SW
100
200
300
400
500
NE 600
Namaqualand Metamorphic Complex
Marydale
Kimberley
Fig. 2: % G10
less than 40 gt analysed
40 to 120 gt analysed
more than 120 gt analysed
BBFZ
DBFZ
Fig. 3: % eclogite
< 5% mostly in Gp 2 kimberlites
Fig. 4: Gt Cr2O3
maximum Cr2O3 in gt (wt%)
average Cr2O3 in gt (wt%)
Fig. 5: MnO in gt
Grp 1 kimberlites
Grp 2 kimberlites
Fig. 6: Forsterite at 950°C
error
less than 40 gt analysed
40 to 120 gt analysed
more than 120 gt analysed