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Diamond prospectivity of the Rehoboth Terrane, southern Africa, based on integrated geophysical and geochemical constraints on its Proterozoic lithospheric structure and evolution

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The Rehoboth Terrane of southern Africa, accreted to the western margin of the Archaean Kaapvaal Craton (Figure 1) and largely hidden beneath thick Quaternary Kalahari sand cover, remains somewhat enigmatic as much of the terrane characterisation is derived through indirect observation and is relatively poorly constrained. The Rehoboth's age of stabilisation (Proterozoic versus Archaean), lithospheric thickness, mantle geotherm and diamond prospectivity are all subjects of ongoing debate.

While a large number of kimberlite pipes have been identified within the Rehoboth Terrane, in the Gibeon and "Gordonia" fields, none are reported to be diamondiferous. Early reports of the extensively prospected Rietfontein pipe in the Gordonia Field (Figure 1) referred to it as being diamondiferous (e.g., Gurney *et al.*, 1971), but more recent discussions suggest that it is in fact non-diamondiferous (Gurney, 1984; Dawson, 1989, Appleyard *et al.*, 2007).

In this paper we present new deep lithospheric images of the Rehoboth Terrane, provided by both 2-D magnetotellurics (MT) and 3-D Rayleigh-wave seismic tomography. These geophysical images are integrated with mantle geotherms derived from the geochemical analysis of peridotite xenoliths from the Kimberley and Gibeon kimberlite fields (Grütter and Moore, 2003) to provide a more robust estimate of the relative thickness of the Rehoboth lithosphere with respect to that of the Kaapvaal Craton, and to address the diamond prospectivity of the Rehoboth Terrane.

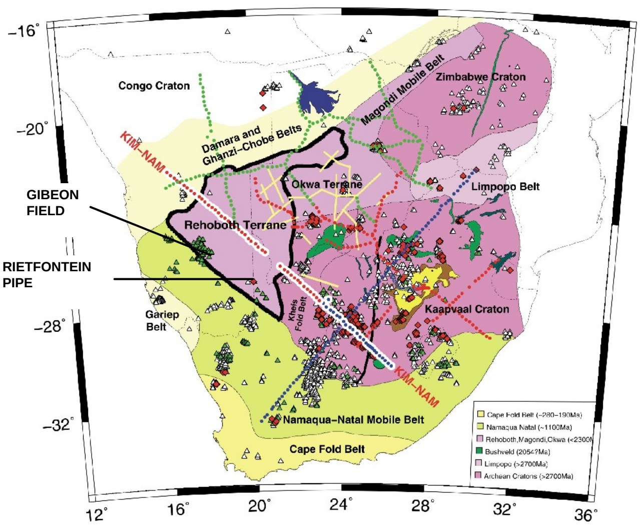

Figure 1. Simplified geological map of southern Africa showing the locality of the Rehoboth Terrane and kimberlite occurrences (red diamonds = known diamondiferous, green triangles = known non-diamondiferous, white triangles = unknown or unspecified in databases). SAMTEX magnetotelluric sites are also shown (red, green and blue dots). Terrane boundaries courtesy of Sue Webb, University of the Witwatersrand, Johannesburg.

Constraints from geochronology

Several key observations from geochemistry suggest an early Proterozoic stabilisation age for the Rehoboth lithosphere. The oldest Rehoboth crustal ages yet identified are between 2.3 and 1.7 Ga (Nd model and zircon ^{207}Pb/^{206}Pb ages, Ziegler and Stoessel, 1991) for the Weener Intrusive Suite on the northern margin the terrane. Mantle peridotite xenoliths from the Gibeon kimberlite field provide model Re depletion ages (indicating the age of partial melt extraction from the mantle) of between 2.2 and 2.0 ± 0.2 Ga (Hoal *et al*., 1995), which are ~1 Ga younger than those observed on the Kaapvaal Craton (Boyd *et al*., 2004). The Rehoboth xenoliths are also less depleted, reflecting lower degrees of partial melting: Mg# ≈91.8, versus 92.6 for the Kaapvaal (Hoal *et al*., 1995). No Archaean dates have yet been reported for any Rehoboth samples.

Constraints from xenolith thermobarometry

Peridotite xenolith thermobarometry data (Grütter and Moore, 2003) from the Kimberley and Gibeon kimberlite fields constrain lithospheric mantle geotherms at the time of kimberlite eruption (~120 – 80 Ma). A moderately hotter geotherm and thinner lithosphere (defined by the intersection of the geotherms with the mantle adiabat) are inferred for the Rehoboth Terrane compared with the Kaapvaal Craton: ~42.5 to 44 versus ~39 to 41 mWm^{-2}, and ~180 to 192 versus 208 to 226 km respectively (ignoring high temperature xenoliths) (Figure 2).

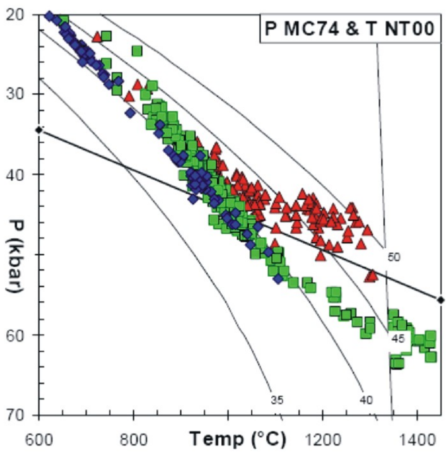

Figure 2. P-T results for peridotite xenoliths from the Gibeon (red), Kimberley (blue) and Northern Lesotho (green) fields (from Grütter and Moore, 2003). The barometer of MacGregor (1974) and thermometer of Nimis and Taylor (2000) are used. Model conductive geotherms (35 to 50 mWm^{-2}) are after Pollack and Chapman (1977), terminating at a mantle adiabat with T_P = 1300°C. The graphite/diamond equilibrium is that of Kennedy and Kennedy (1976).

Constraints from geophysics

Magnetotelluric (MT) traverse KIM-NAM, acquired across the sub-continent and forming part of the broader Southern African MT Experiment (SAMTEX) (Figure 1), has provided a deep 2-D electrical resistivity image that shows significant differences between the lithosphere of the Rehoboth and Kaapvaal terranes (Figure 3). Electrical resistivities, lower by a factor of ~10 beneath the Rehoboth Terrane, are most readily explained by a hotter geotherm and thinner lithosphere (at least ~40 km thinner) in comparison with the eastern Kaapvaal Craton (Figure 4), and are consistent with the xenolith thermobarometric constraints.

The lithosphere beneath the western Kaapvaal Craton, below the Kheis Fold Belt, is also significantly less resistive, and therefore hotter and most likely thinner (perhaps by ~25 km), than that beneath the eastern Kaapvaal Craton (Figure 4).

A new regional 3-D Rayleigh-wave seismic tomography inversion for the African continent, from which a shear-wave velocity profile has been extracted along profile KIM-NAM, reveals significantly reduced S-wave velocities beneath the Rehoboth Terrane (Figure 3) that are also consistent with a hotter geotherm and thinner lithosphere for the Rehoboth.

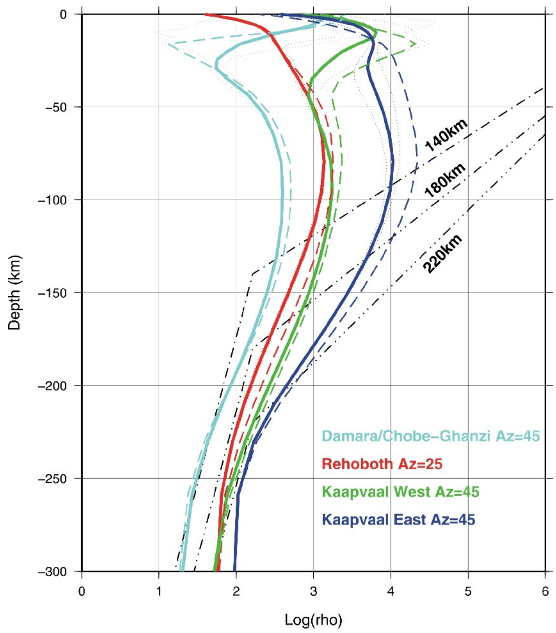

Figure 4. Average electrical resistivity versus depth profiles for geological terranes traversed by SAMTEX profile KIM-NAM. The solid coloured curves are the lateral averages, within each terrane, of the resistivity structure shown in Figure 3. Variance is shown by coloured dashed lines. Predicted resistivity-depth profiles for hypothetical mantle geotherms for different lithosphere thicknesses are shown (black dotted and dashed lines), based on laboratory electrical-conductivity versus temperature and pressure measurements for dry olivine and pyroxene (Constable *et al*., 1992; Xu and Shankland, 1999 and Xu *et al*., 2000).

Conclusions

Relatively hotter, and therefore thinner lithosphere, beneath both the western-most Kaapvaal Craton and the Rehoboth Terrane (at least thinner than the depth of the diamond stability field, both now and at the time of kimberlite eruption), as inferred from the observed subsurface electrical-resistivity and shear-wave velocity images and xenolith thermobarometry, is consistent with the absence of reported diamondiferous kimberlites in both of these areas.

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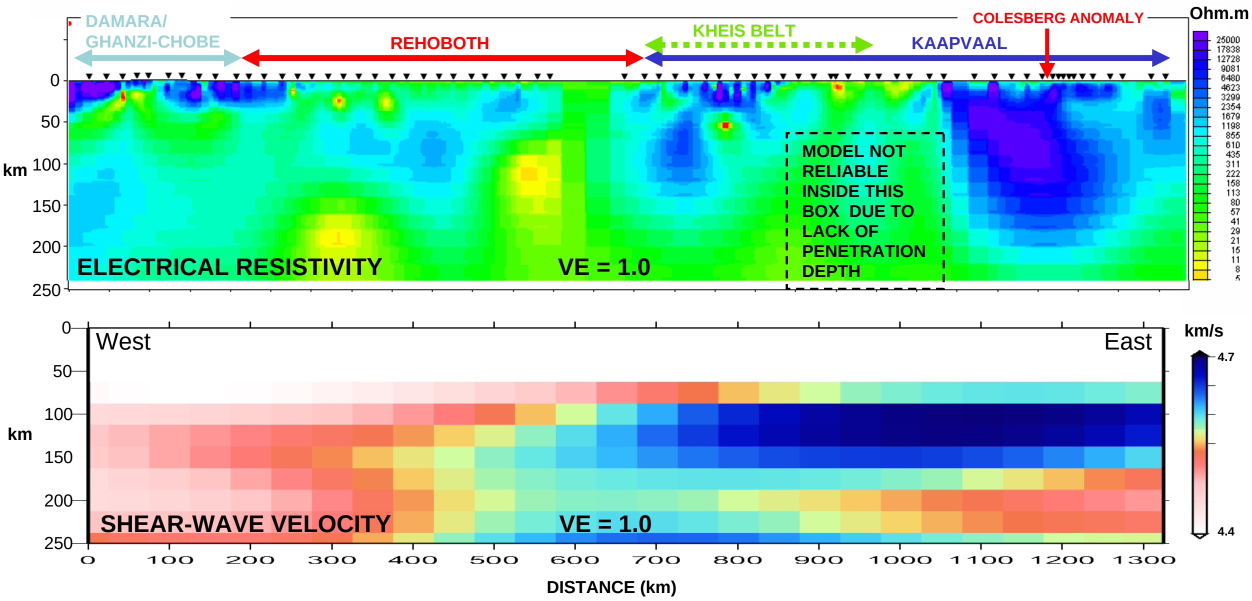

Figure 3. Coincident electrical-resistivity and shear-wave velocity images along SAMTEX profile KIM-NAM. The electrical resistivty image is derived from 2-D inversion of magnetotelluric responses at 60 sites along the profile. The velocity image is derived from a regional 3-D Rayleigh-wave inversion.