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Density structure of the cratonic mantle in southern Africa, kimberlite distribution, mantle velocities, Moho sharpness, and dynamic topography

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We present a new regional model for the density structure of the cratonic lithospheric mantle in southern Africa and discuss it in relation to regional seismic models for the crust and upper mantle, geochemical data on kimberlite-hosted mantle xenoliths, and data on kimberlite ages and distribution. Our calculations of mantle density are based on free-board constraints, account for mantle contribution to surface topography of ca. 0.5-1.0 km, and have uncertainty ranging from ca. 0.01 g/cc for the Archean terrains to ca. 0.03 g/cc for the adjacent fold belts [1]. We demonstrate that in southern Africa the lithospheric mantle has a general trend in mantle density increase from Archean to younger lithospheric terranes. SPT density of the Kaapvaal mantle is typical cratonic, with a subtle difference between the eastern, more depleted, (3.31-3.33 g/cc) and the western (3.32-3.34 g/cc) blocks. The Witwatersrand basin and the Bushveld Intrusion Complex appear as distinct blocks with an increased mantle density (3.34-3.35 g/cc) with values typical of Proterozoic rather than Archean mantle. We attribute a significantly increased mantle density in these tectonic units and beneath the Archean Limpopo belt (3.34-3.37 g/cc) to melt-metasomatism. The Proterozoic Kheis, Okwa and Namaqua-Natal belts and the Western Cape Fold Belt with the late Proterozoic basement have an overall fertile mantle (ca. 3.37 g/cc) with local (100-300 km across) low-density (down to 3.34 g/cc) and high-density (up to 3.41 g/cc) anomalies. High (3.40-3.42 g/cc) mantle densities beneath the Eastern Cape Fold belt require the presence of a significant amount of eclogite in the mantle, such as associated with subducted oceanic slabs.

We find a strong correlation between the calculated density of the lithospheric mantle, the crustal structure, the spatial pattern of kimberlites and their emplacement ages [2].

(1) Blocks with the lowest values of mantle density (ca. 3.30 g/cc) are not sampled by kimberlites and may represent the "pristine" Archean mantle.

(2) Young (<90 Ma) Group I kimberlites sample mantle with higher present-day density (3.35±0.03 g/cc) than the older Group II kimberlites (3.33±0.01 g/cc), but the results may be biased by incomplete information on kimberlite ages.

(3) Diamondiferous kimberlites are more typical of a low-density cratonic mantle (3.32-3.35 g/cc), while non-diamondiferous kimberlites sample mantle with a broad range of density values. Diamondiferous kimberlites that sample a dense mantle (3.35-3.37 g/cc) are all older than 200 Ma.

(4) Kimberlite-rich regions have a strong seismic velocity contrast at the Moho, thin crust (35-40 km) and low-density (3.32-3.33 g/cc) mantle, while kimberlite-poor regions have a transitional Moho, thick crust (40-50 km), and denser mantle (3.34-3.36 g/cc). We explain this pattern by a lithosphere-scale (presumably, pre-kimberlite) magmatic event in kimberlite-poor regions, which affected the Moho

sharpness and the crustal thickness through magmatic underplating and modified the composition and rheology of the lithospheric mantle to make it unfavourable for consequent kimberlite eruptions.

(5) Density anomalies in the lithospheric mantle show weak inverse correlations with seismic Vp, Vs velocities at 100-150 km depth, but only when averaged over large tectonic blocks, suggesting that density-velocity relationship in the cratonic mantle is strongly non-unique.

References:

[1, 2] Artemieva I.M. and Vinnik L.P. (2016) Gondwana Research