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Reconciling Electromagnetic, Seismic and Xenolith Constraints on Lithospheric Thickness and Composition of the Kaapvaal Craton, South Africa

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Much of the long-running debate regarding the depth extent of the continental lithosphere beneath Archaean shield areas has focussed on the Kaapvaal Craton of South Africa. Our recent magnetotelluric surveys across the Kaapvaal Craton, as part of the Southern African Magnetotelluric Experiment (SAMTEX), indicate a lithospheric thickness of the order of 220 km or greater for the central core of the craton. In contrast, a recently published S-wave receiver function study and several surface wave studies suggest that the Kaapvaal lithosphere is characterised by an approximately 160 km thick high-velocity "lid" underlain by a low-velocity layer between 65 – 150 km thick, with the base of the high-velocity lid inferred by some to represent the "lithosphere-asthenosphere boundary". Other body-wave, surface wave and S-wave receiver function studies in the area suggest that the (high-velocity) lithosphere is substantially thicker, in excess of 220 km for the most part.

Evidence from mantle xenolith pressure-temperature arrays derived from Mesozoic kimberlites found across the Kaapvaal Craton requires that the base of the "thermal" lithosphere (i.e. the base of the thermal boundary layer above which a conductive geotherm is maintained) be at least 220 km deep, if observed mantle geotherms in the range 35 – 38 mW/m2 are to be accounted for. The presence of richly diamondiferous kimberlites across the Kaapvaal Craton is also impossible to reconcile with a 160 km lithospheric thickness: the top of the diamond (pressure-temperature) stability field is deeper than 160 km for the mantle geotherm associated with a 160 km lithospheric thickness.

In the work presented here, we use the recently developed LitMod software package to derive both seismic velocity and electrical resistivity models for the lithosphere that are fully chemically, petrologically and thermodynamically consistent, and assess whether these apparently disparate views of the Kaapvaal lithosphere – provided by seismic, magnetotelluric and xenolith studies – can be reconciled. We address directly several key issues: (i) whether a 160 km lithospheric thickness (and its associated temperature and pressure variation with depth) is "internally" consistent with the high (> 4.7 km/s) S-wave velocities predicted for the seismic high-velocity lid, given typical Kaapvaal geochemical compositions from xenolith analyses, (ii) whether a 160 km lithospheric thickness and its associated electrical resistivity variation with depth is consistent with observed magnetotelluric responses, and (iii) whether the observed (negative) mantle S-to-P conversion event at 160 km depth in one S-wave receiver function study can be explained by compositional layering within the Kaapvaal Craton, given that the geochemistry of xenoliths from younger Group I kimberlites provides evidence for chemical refertilisation of the lithosphere in the depth range 160 – 200 km.