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Inferring upper-mantle temperatures from seismic and geochemical constraints: Implications for Kaapvaal craton

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Based on self-consistent thermodynamic approach, we infer the temperature distribution models at 100 to 300 km depth for the normal upper mantle and beneath the Kaapvaal craton from P- and S-wave velocities and geochemical constraints (garnet-bearinglherzolite xenoliths, average composition of garnet peridotite and primitive mantle composition). For the computation of the phase diagram for a given chemical composition, we have used a method of minimization of the total Gibbs free energy combined with a Mie-Grüneisen equation of state. Our forward calculation of phase diagram, seismic velocities and density and inverse calculation of temperature includes anharmonic and anelastic parameters as well as mineral reaction effects, including modes and chemical compositions of coexisting phases. Sensitivity of density and velocities to temperature, pressure and composition was studied. Calculated velocities are between the fastest and slowest seismic models reported for southern Africa. The estimated temperatures depend rather strongly on bulk composition and proportion of phases stable at various depths of the upper mantle. The relatively small differences between the xenolith compositions translate into appreciable variations in inferred temperature. Temperatures inferred from the IASP91 model and from some of regional models beneath the Kaapvaal craton, irrespective of the composition model, display an inflection with a negative temperature gradient at depths below $\sim$200-220 km, leading to unrealistic temperature behaviour. We find that the upper mantle (normal and cratonic) cannot be treated as uniform in terms of bulk composition because a fixed uniform composition leads to a non-physical behaviour of geotherms. A mantle with a uniform composition as well as a sharp change in composition from depleted garnet peridotite to fertile pyrolitic material seems unable to explain inflexions

of geotherms as well as an anticorrelated behaviour for T_P and $T_S$inferred from absolute P- and S-velocities. To avoid temperature inflexions, a continuous change in composition and an increase in fertility (gradual increase in FeO, Al_2O_3 and CaO content) at depths between 200 and 300 km are required to get monotonous temperature profiles. The mantle beneath the Kaapvaal craton is chemically stratified: an upper layer at depths between 100 and ∼200 km consisting of depleted garnet peridotite and a lower layer (below ∼200-220 km) made of a more fertile material.

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