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Constraining the composition and thermal state of lithospheric mantle from inversion of seismic data: Implications for the Kaapvaal and Siberian cratons

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Quantitative estimation of the temperature distribution in the Earth's mantle is a key problem in petrology and geophysics. In this study, we discuss the method of estimating temperature, composition and thickness of the subcontinental lithospheric mantle beneath some Archean cratons from absolute seismic velocities. The phase composition and physical properties of the lithospheric mantle were modelled within the Na2O-TiO2-CaO-FeO-MgO-Al2O3-SiO2 system including the non-ideal solid solution phases. 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. Inverse code computes the temperature distribution in the upper mantle from seismic and compositional constraints. The output results contain the self-consistent information on phase assemblages, densities and velocities. The approach used here requires a small number of thermodynamically defined parameters and has important advantages over earlier procedures, which contain no information about entropy, enthalpy and Grüneisen parameter. We inverted for temperature the recent P and S velocity models of the Kaapvaal craton as well as the IASP91 reference Earth model. Several long-range seismic profiles were carried out in Russia with Peaceful Nuclear Explosions (PNE). The velocity models from PNEs recorded along these profiles were used to infer upper mantle temperature profiles beneath the Siberian craton. The seismic profiles were inverted on the basis of low and high temperature xenoliths of garnet peridotites from kimberlite pipes of the cratons in order to gain insights into the temperature sensitivity to variations in the composition and mineralogy of xenoliths. Such a test can provide constraints on the compositional (vertical and lateral) heterogeneity of the upper mantle. 1D and 2D thermal profiles of the lithospheric mantle for the Kaapvaal and Siberian cratons inferred from the absolute seismic velocities are discussed. We derive a lithosphere thickness of roughly 275 km for the Kaapvaal craton and 300-350 km for the Siberian craton by the intersection of the calculated temperature profile in the conductive region with the potential adiabat.