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Constraints on lithospheric temperatures from a comparison of laboratory derived seismic velocities with shear wave models

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The largest seismic velocity contrast observed in the upper mantle by regional or global models occurs between ocean basins and continental cratons. However, in comparison to ocean basins, geotherms for continental cratons are less well constrained. The best constraints come from heat flow measurements, but these only fix the temperature gradients in the shallow crust. Temperatures in the deeper crust and lithosphere are estimated from the distribution of heat-producing elements and geothermobarometry. An important question regarding the structure of continents is the depth extent of continental roots.

We have measured shear modulus and attenuation of polycrystalline olivine as a function of temperature at seismic periods. The data from four samples ranging in mean grain size by more than an order of magnitude have been fitted to an extended Burgers model that allows extrapolation of our measurements to the larger grain sizes expected in the upper mantle. An important experimental observation is that polycrystalline olivine behaves nearly elastically at temperatures below about 900 deg. C at seismic periods. Above this temperature viscoelastic processes cause attenuation and shear modulus reduction, resulting in much larger and period-dependent modulus variation relative to lower temperatures or high frequencies.

With our experimentally determined temperature dependence of the shear modulus we can calculate 1D shear velocity profiles for geotherms from a range of tectonic settings and compare them to seismologically determined velocity structures. For oceans geotherms are calculated for a conductively cooling plate. The resulting velocity profiles give very good fits to seismological observations including the age-dependent structure of the low velocity zone (LVZ). The LVZ does not require the presence of melt or water but can be explained solely by sub-solidus mechanisms.

For continents the geotherms are constructed from measured heatflow values and grid-searching a prescribed range of heat-production values in a 2-layer crust plus lithospheric heat production. These geotherms are then used to calculate a shear velocity profile and its misfit to seismological models. The resulting best-fit geotherms show that most of the surface heatflow in stable continental regions is generated in the crust, and that heatflow from the convecting mantle into the lithosphere is negligible.

A potential problem for seismological surface wave models in their ability to resolve the depth of cratonic roots is their diminishing resolution with depth. Available seismic studies show no pronounced low velocity zone beneath cratons, although a mild velocity decrease is observed, which places strong constraints on the lithospheric temperature distribution. For geotherms which join the adiabat at a depth of 200 km or shallower a pronounced low velocity zone is unavoidable. For geotherms which join the adiabat much deeper than 350 km a decrease in velocity below the lid is absent. Some seismological models thus imply that cratons (defined by sub-adiabatic temperatures) extend to the transition zone.