Supplemental Material: Temperature-Velocity Models

1. Jackson and Faul, 2010

The Jackson and Faul, model is described in detail in Jackson and Faul (2010) and Faul and Jackson (2005). They use an extended Burgers model based on torsional forced-oscillation measurements to describe the anharmonic and anealstic effects of temperature on the mantle shear modulus. They base their model on measurements made at mantle temperatures and frequencies but at smaller grain sizes and lower pressures. As such, they extrapolate their measurements to mantle pressures and grain sizes.

The anharmonic component of ­­the shear modulus is determined by the equation:

where GU is the unrelaxed shear modulus, T is temperature, P is pressure, and TR and PR are the reference pressure and temperature, respectively.

Values of GU = 66.5 GPA; MPa K-1; are taken from Bass (1995). TR = 900° C and PR = 0.2 GPa were used.

The relaxed shear modulus is calculated using the equation:

where:

and

ω is angular frequency, is the anelastic relaxation strength, D is a function defining the distribution of anelastic relaxation times, and τH and τL are the limits for the distribution of anelastic relaxation times. τ is relaxation time, which is a function of pressure, temperature, grain size, activation energy, and activation volume.

In our calculations, grain sizes are varied as discussed in the main text. An input of 360 kJ/molis used for activation energy and an input of 1 cm3/molis used for activation volume. The code for forward modelling velocities was downloaded from <http://web.mit.edu/hufaul/www/Anelasticity.html> and the remaining inputs are given there. For this methodology, mantle temperatures were determined using a grid-search to minimize misfit between measured and predicted velocities at given pressures.

1. Goes et al. (2000)

Goes et al., (2000), use Voigt-Reuss-Hill averaging to calculate the anharmoic shear modulus based on models of upper mantle composition. They base their anelasticity component on mineral physics data. We use their same methodology and inputs for the anharmonic component which is determined by the equation:

where G is the shear modulus at reference pressure and temperature, PR and TR . Ti*s* the temperature, P is the pressure, and G is determined are determined by Voigt-Ruess-Hill averaging of common mantle minerals. The input composition and elasticity model is given in their work (Goes et al., 2000).

We use the following equation from Goes et al., (2000) to calculate to shear-wave anelasticity effect (*QS*):

where ω is the seismic frequency, *a* is the exponent describing the frequency dependence of the attenuation, R is the gas constant, E is the activation energy, V is the activation volume, H is the activation enthalpy, A is a scaling factor, and *d* is grain size.

For the anharmonic component we use updated anelasticity inputs from Cammarano (2003) where A = 0.0013, a = 0.26, E = 424 kJ/mol, V = 6 cm3/mol, d = 1 mm.

In this approach, the shear velocity is calculated using the equation:

To implement this model, we use the same Newton–Raphson iteration method as Goes (2000) and minimize the difference between predicted and observed velocities to calculate temperature.

1. McCarthy et al., 2010

McCarthy et al. (2011) measure the elastic properties of polycrystalline organic borneol, an analogue for mantle peridotite and scaled their results to seismic conditions using the Maxwell frequency. They fit their data using a sixth-degree polynomial function to calculate their compliances J1 and J2. We make the assumption that QS-1 « 1 in our calculations, where QS-1 is surface wave attenuation. This is done to simplify the relationship between temperature and shear velocity. In this approximation shear velocity is determined by the equation:

where:

where *fn* is the normalized frequency, T is temperature, P is pressure, *f* is frequency, and *d* is grain size. a0 = 0.55097, a1 = 0.054332, a2 = −0.0023615, a3 = −5.7175 × 10−5, a4 = 9.9473 × 10−6, a5 = −3.4761 × 10−7, and a6 = 3.9461 × 10−9, which were determined using the sixth‐degree polynomial fit of their experimental data.

JU is given by the equation:

where G is unrelaxed shear modulus.

*fn*  is given by the equation:

where is the reference time scale given by:

*dr* is reference grain size, η0 is related to viscosity, m is the grain size exponent, TR is reference temperatures, PR is reference pressure, E is activation energy, V is activation volume, and R is the gas constant.

We use inputs of *d* = 1 mm, *dR* = 1 mm, η0 = 6.6 × 1019 Pa s, m = 3, TR = 1200° C , PR = 1.5 GPa, E = 505 kJ/mol, V 1.2 cm3/mol based on the inputs in their work. To implement this model, we use the Newton–Raphson iteration method and minimize the difference between predicted and observed velocities to calculate temperature.

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