Seismic constraints on the physical reference structure of the Earth's mantle

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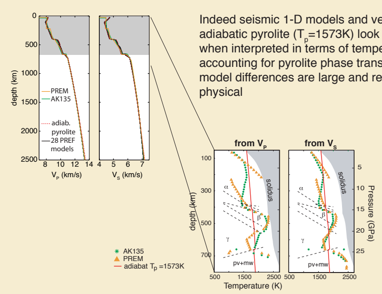
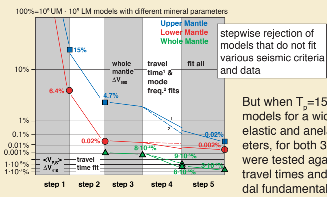
Motivation/ Previous work

Usual assumption: tomographic anomalies are relative to an average for whole mantle convection, i.e. pyrolite with phase transitions along an adiabat with potential temperature of 1525-1725K



Indeed seismic 1-D models and velocities for adiabatic pyrolite (T_p=1573K) look similar.. But when interpreted in terms of temperature (while accounting for pyrolite phase transitions) the model differences are large and results nonn-physical



stepwise rejection of models that do not fit various seismic criteria and data

But when T_p=1573K-adiabatic pyrolite models for a wide range of values of elastic and anelastic mineral parameters, for both 3[rd] and 4[th] order EOS, were tested against global P and S travel times and spheroidal and toroidal fundamental mode frequencies, extremely few were found to be compatible with the seismic data

Main sources of seismic incompatibility of the T_p1573 adiabatic-pyrolite models are:
(1) too high $V_{P,S}$ in wadsleyite field and (2) too high lower mantle $\partial V_{P,S}/\partial z$

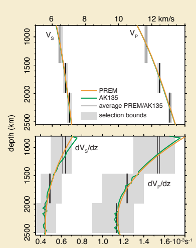
Possible causes for misfit: (A) uncertainties in the EOS and phase diagram not accounted for
(B) average physical structure deviates from adiabatic-pyrolite
Some preliminary results from exploring these two possibilities are shown.

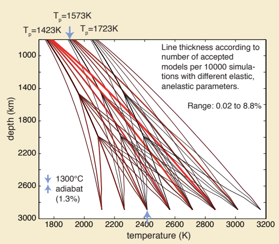
(B) Alternative physical structures?

Lower mantle temperatures

As a first step, we tested alternative LM thermal structures with various gradients and changes in gradients. Composition is not changed from pyrolite in these tests. However, to dynamically sustain strongly non-adiabatic gradients other physical properties than temperature will have to change as well.

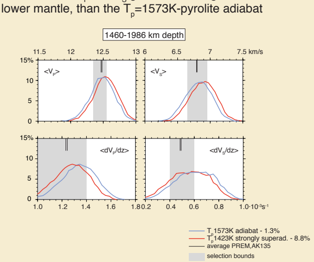
We use a single step selection on seismically well constrained properties, using liberal bounds: average velocity and gradients in 3 LM depth intervals. Tests of travel time fits may allow us to further tighten these bounds.





Superadiabatic structures with lower potential temperatures appear to be seismically favored over a T_p=1573K adiabat.

The preferred structures have similar average velocities but lower V_p and V_s gradients throughout the lower mantle, than the T_p=1573K-pyrolite adiabat



(A) Uncertainties in phase diagrams/ EOS

Upper mantle tests

In our previous work, elastic parameters for upper mantle minerals were linearly extrapolated to high temperature (LT), and uncertainties in pyrolite composition and the phase diagram were not taken into account. Here, we investigate the effects of a non-linear temperature extrapolation (NT), and of variations in pyrolite composition on seismic velocities. An illustration of how large model differences are is provided by travel time calculations.

- AK135
- AVE-LT-PREM crust

A model with average properties (AVE) does not fit upper mantle travel times

- PREF-LT-PREM crust

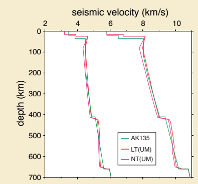
But there are some combinations of elastic and anelastic parameter values (PREF) within the uncertainties that give a reasonable fit.

- AVE-LT-AK135 crust

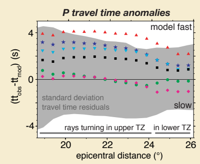
A continental crustal structure as used in AK135 further improves the travel-time fit.

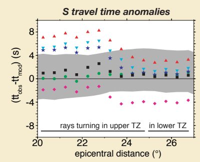
- AVE-NT(TZ)-PREM crust
- AVE-NT(all UM)-PREM crust

Although several published high-T elastic parameter data are more compatible with LT, a non-linear T- extrapolation, NT, significantly improves the travel-time fit.

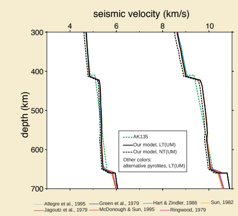


Temperature extrapolation:
$M = K_s$ or G
LT: $M(T,P_0)=M(T_0,P_0)+\partial M/\partial T\cdot(T-T_0)$
NT: $M(T,P_0)=M(T_0,P_0)\cdot[\rho(T)/\rho(T_0)]^{\delta_M}$, $M_\rho=[\partial \ln M/\partial \ln \rho]_P$





Variations in pyrolite composition and accompanying changes in the phase diagram do not change velocities very strongly.

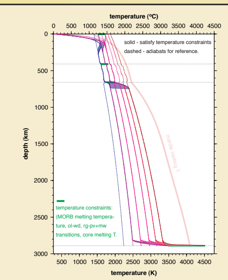


In sum: the large uncertainties in how upper mantle T-derivatives vary with T (and P) can be important, while the seismic effect of uncertainties in pyrolite composition and associated changes in the phase diagram are rather small.

Further work

(A) EOS/Phase diagrams
- **Uncertainties of lower mantle EOS, which are larger than in the upper mantle**
- **Uncertainties in lower mantle phase diagram (Fe- partitioning and Al component)**

(B) Alternative physical structures
- **Tests against seismic data to define seismically well-determined characteristics of 1-D structure**
- **Biases of lower mantle 1-D structure due to 3-D anomalies**
- **Variations in chemistry in the deep mantle**
- **Alternative upper mantle (thermal and possibly compositional) structures**



Sketch of thermal profiles that satisfy temperature constraints. Tests will have to reveal whether things like a "plume-fed" asthenosphere and a boundary layer at 660 km are seismically permissible.

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