TESTING WHOLE MANTLE PLUMES SEISMICALLY

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August, 2005

Motivation

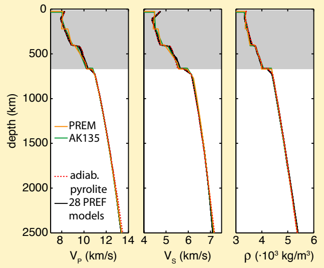
Interpretations of tomographic or other data derived models do not allow full assessment of uncertainties

Therefore, tests directly against seismic and other data are required to accept or reject hypotheses for the physical state of the mantle. Two first steps towards such an approach are illustrated here

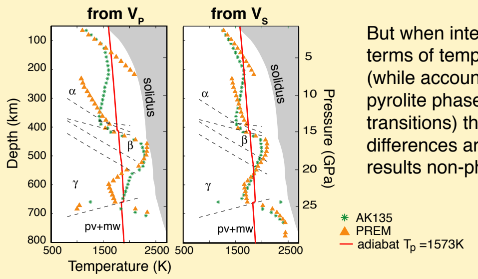
Testing the mantle's physical background structure

Model interpretation

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 1573-1673K



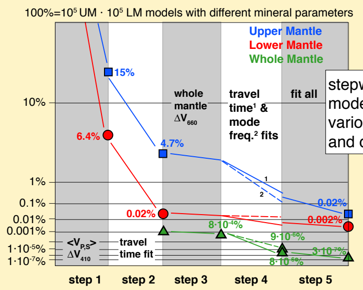
Indeed seismic 1-D models and velocities for adiabatic pyrolite (T_p=1573K) look similar.



But when interpreted in terms of temperature (while accounting for pyrolite phase transitions) the model differences are large and results non-physical

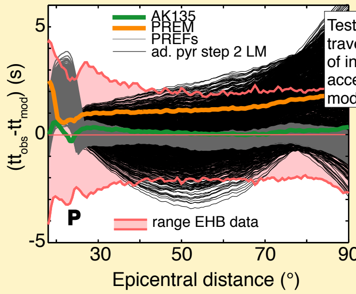
These models are non-unique solutions dependent on chosen parametrization =>
Is an adiabatic pyrolite model with T_p=1573K compatible with global seismic data that the 1-D models were derived for?

Hypothesis test against data

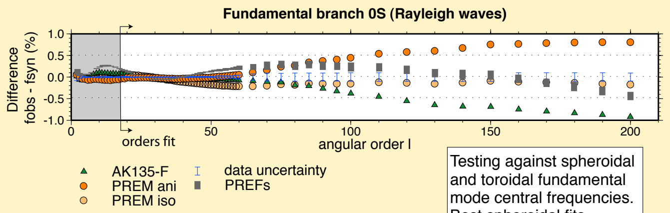


stepwise rejection of models that do not fit various seismic criteria and data

Synthetic velocity models for adiabatic pyrolite were made for a wide range of values of the elastic, and anelastic mineral parameters, using 3rd-4th order Birch-Murnaghan EOS, linear/Grüneisen T extrapolation



Testing against P & S travel times (tt). P fits of initial and the few accepted (PREF) models



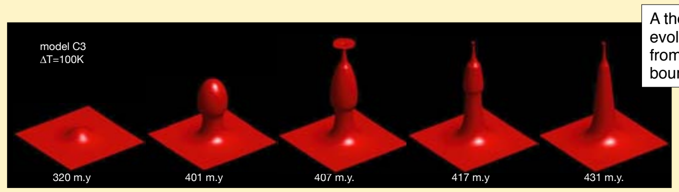
Testing against spheroidal and toroidal fundamental mode central frequencies. Best spheroidal fits

The very small number of acceptable models indicates that our physical reference structure is incompatible with seismic data in
(1) the transition zone (needs to be slower below 400 km) and
(2) the lowermost mantle (above D") (velocities need to increase more gradually with depth).

Possible solutions: (a) larger uncertainties in the EOS - ∂/∂T? ∂/∂T∂P? lower mantle extrapolations?
(b) deviations from this physical model - chemical variability? significant 3-D structure?

Synthetic seismic structures for thermal whole mantle plumes

Temperature

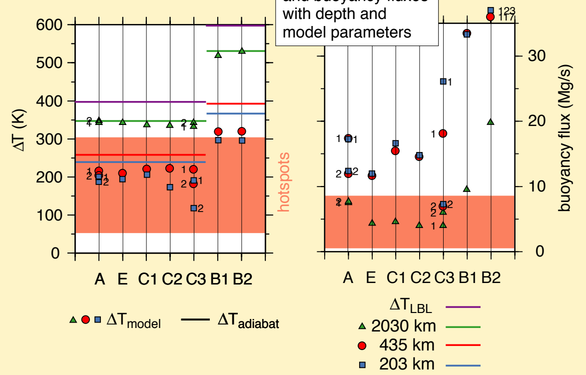


A thermal plume evolving dynamically from a hot thermal boundary layer

Thermal whole mantle plumes with temperature and pressure dependent mantle viscosity, expansivity, conductivity are dynamically predicted to be:

(1) 500 -800 km wide in the lower mantle
(2) narrowing in the upper mantle to 50-100 km due to decreased viscosity and activation of stress-dependent creep
(3) rising almost adiabatically at speeds that are about 0.1-1m /yr
(4) have thermal anomalies that mirror those of their spawning boundary layer, which requires that part of the expected ~1500K deep TBL is stabilized, if plume sublithospheric ΔT is as low as inferred at hotspots..
(5) very slow to initiate (> 0.4 b.y.) without external forcing (e.g. pushing by subducted material), for hotspot-inferred ΔT.
(6) have buoyancy fluxes of at least 3 Mg/s. A diffusively growing thermal boundary layer above the CMB can support < 10 such high flux plumes.
(7) difficult to bend in the lower mantle, but easy to deflect in the upper mantle

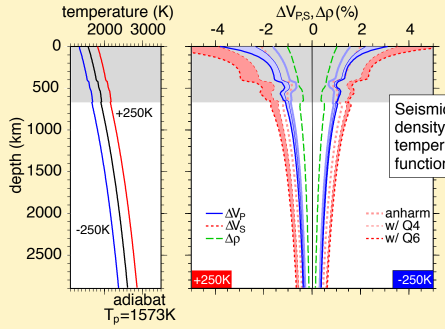
changes in plume excess temperatures and buoyancy fluxes with depth and model parameters



A - basic model
B - hotter ΔT_{LBL}
E - constant k

C1 - stronger ∂η/∂T in UM
C2 - stronger ∂η/∂T in UM/LM
C3 - strongest ∂η∂T

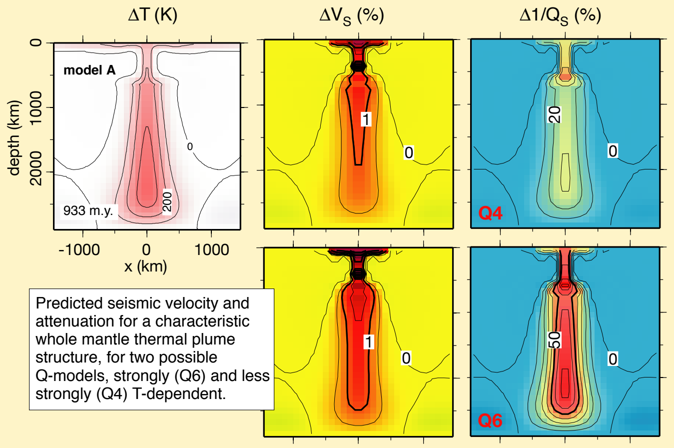
Velocity



Seismic velocity and density sensitivity to temperature as a function of depth

The dynamically predicted properties agree with:

(1,2) tomographically imaged plume width in upper and lower mantle
(3) seismic V anomaly amplitudes expected for adiabatically rising plumes with low ΔT as inferred from hotspots, and associated seismic Q anomalies
(4) seismic indications for dense chemical heterogeneity in deep mantle, which may be able to stabilize part of the deep TBL resulting in low and variable plume ΔT
(5) concentration of hotspots away from subduction anomalies in the deep mantle
(6) the small number of hotspots that have a deep seismic anomaly (although sublithospheric B needs to be moderated by a dense component and/or plume lithosphere interaction (small-scale convection?)
(7) imperfect hotspot-track age trends



Predicted seismic velocity and attenuation for a characteristic whole mantle thermal plume structure, for two possible Q-models, strongly (Q6) and less strongly (Q4) T-dependent.

Although seismic images agree with many of the characteristics of thermal whole mantle plumes, additional chemical complexity seems likely => Need thermo-chemical hypothesis tests