EARTH'S TRANSITION ZONE

Lars Stixrude

Transition Zone

- Recognized early on as an unusual part of the mantle
- Characterized by large velocity gradients
- Discontinuities not resolved in early studies

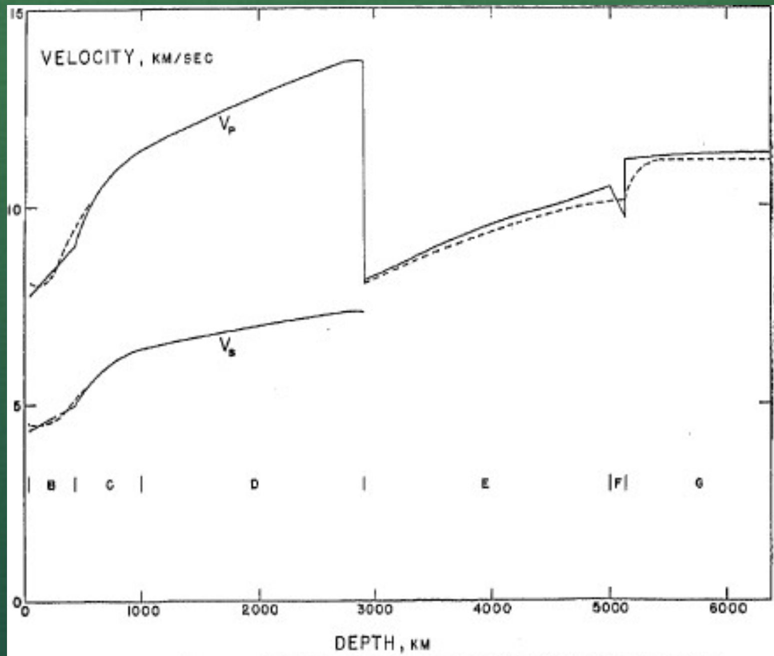
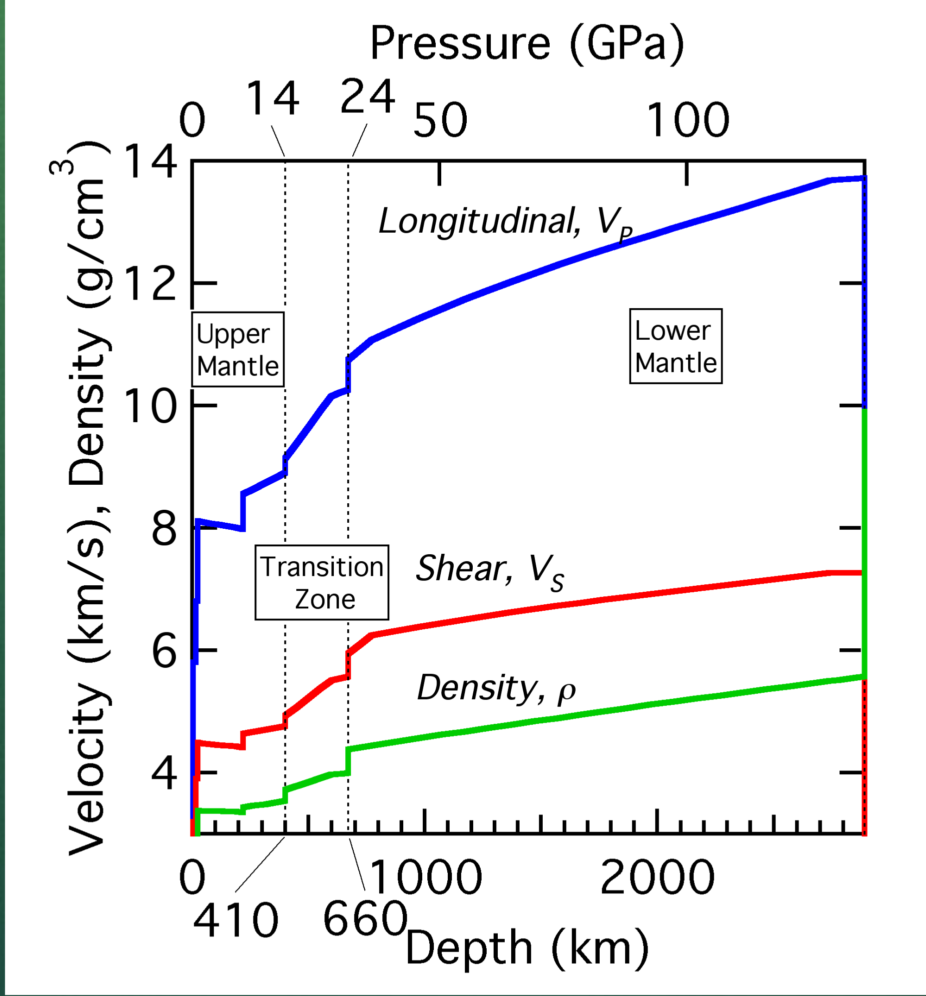


FIG. 1—SEISMIC VELOCITIES AS FUNCTION OF DEPTH

Birch (1952) after Jeffreys, Bullen, Gutenberg

Transition Zone

- Defined seismologically
- Discontinuities in seismic wave velocities at depths of 410 km and 660 km
- Pressure ranges from 14 GPa to 24 GPa
- Average temperature varies with depth from approximately 1800 K to 1900 K



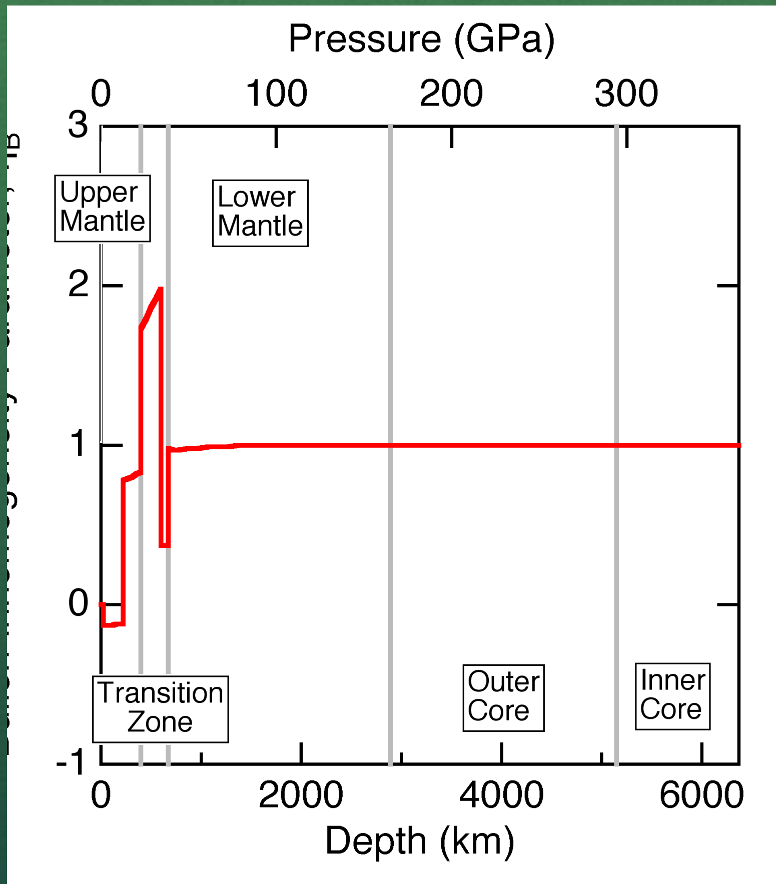
Dziewonski & Anderson (1981) PEPI

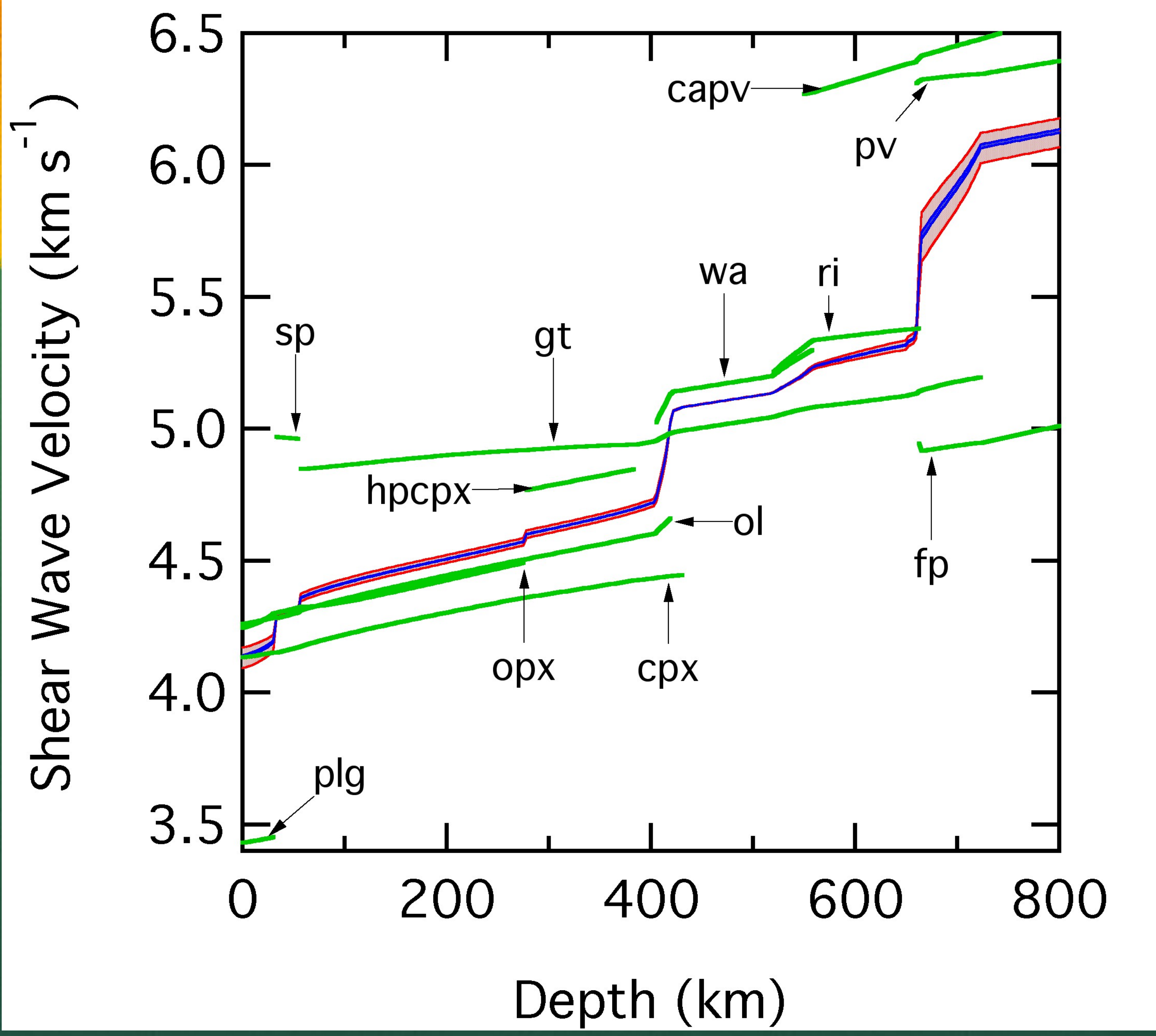
Origin of Steep Gradient

- Compare density gradient to that of homogeneous, adiabatic medium
- Bullen inhomogeneity parameter

$$\eta = \frac{\phi}{\rho g}\frac{\partial \rho}{\partial z}$$

- Differs from unity in the transition zone
- Inhomogeneity in entropy, bulk composition, or phase



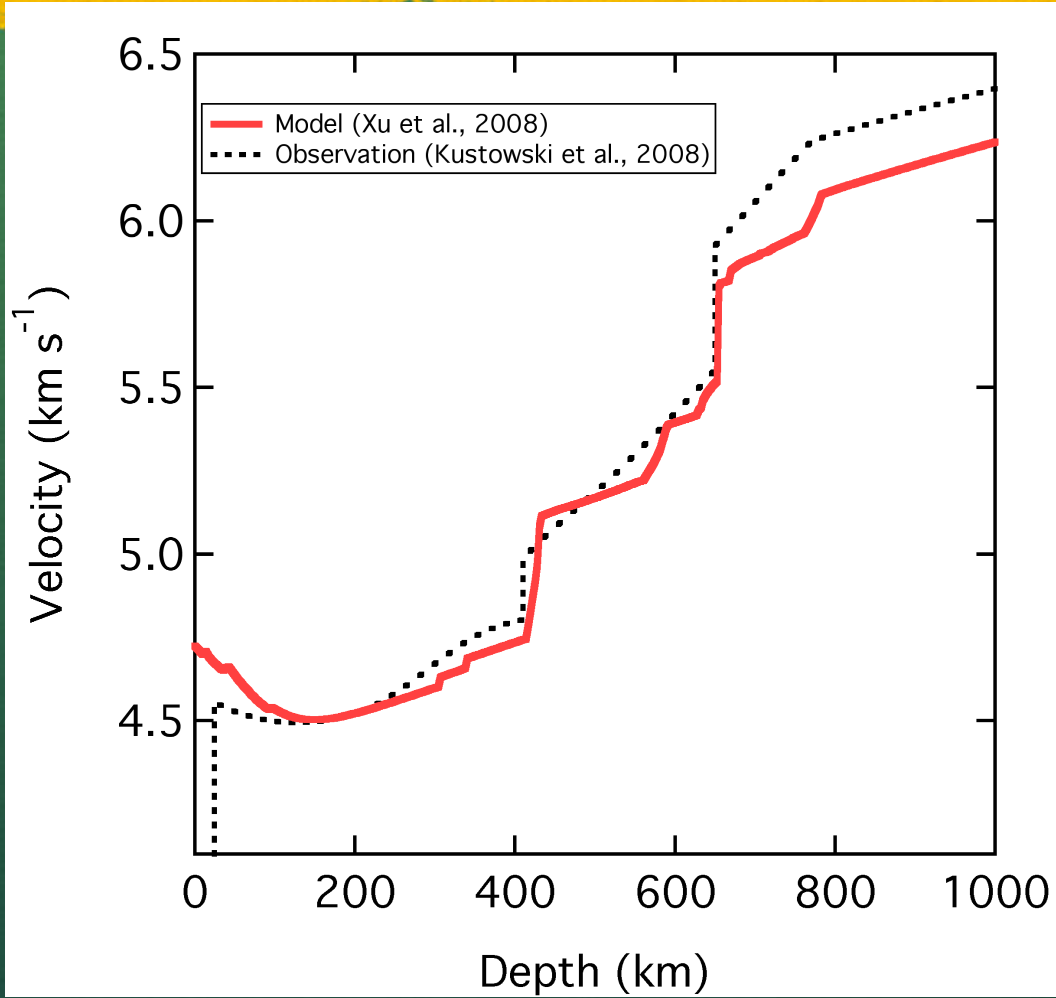


Plagioclase (plg); Spinel (sp); Olivine (ol); Orthopyroxene (opx); Clinopyroxene (cpx); Garnet (gt); Wadsleyite (wa); Ringwoodite (ri); akimotoite (ak); Mg-perovskite (mgpv); Ca-perovskite (capv); Ferropericlase (fp)

Stixrude & Lithgow-Bertelloni (2007) EPSL

Origin of Transition Zone Gradient

- Phase transformations
- Agreement between seismology and a model that assumes homogeneous entropy and bulk composition is reasonable
- May not be a unique interpretation
- Heterogeneity in entropy and/or composition may exist
- Use more observations

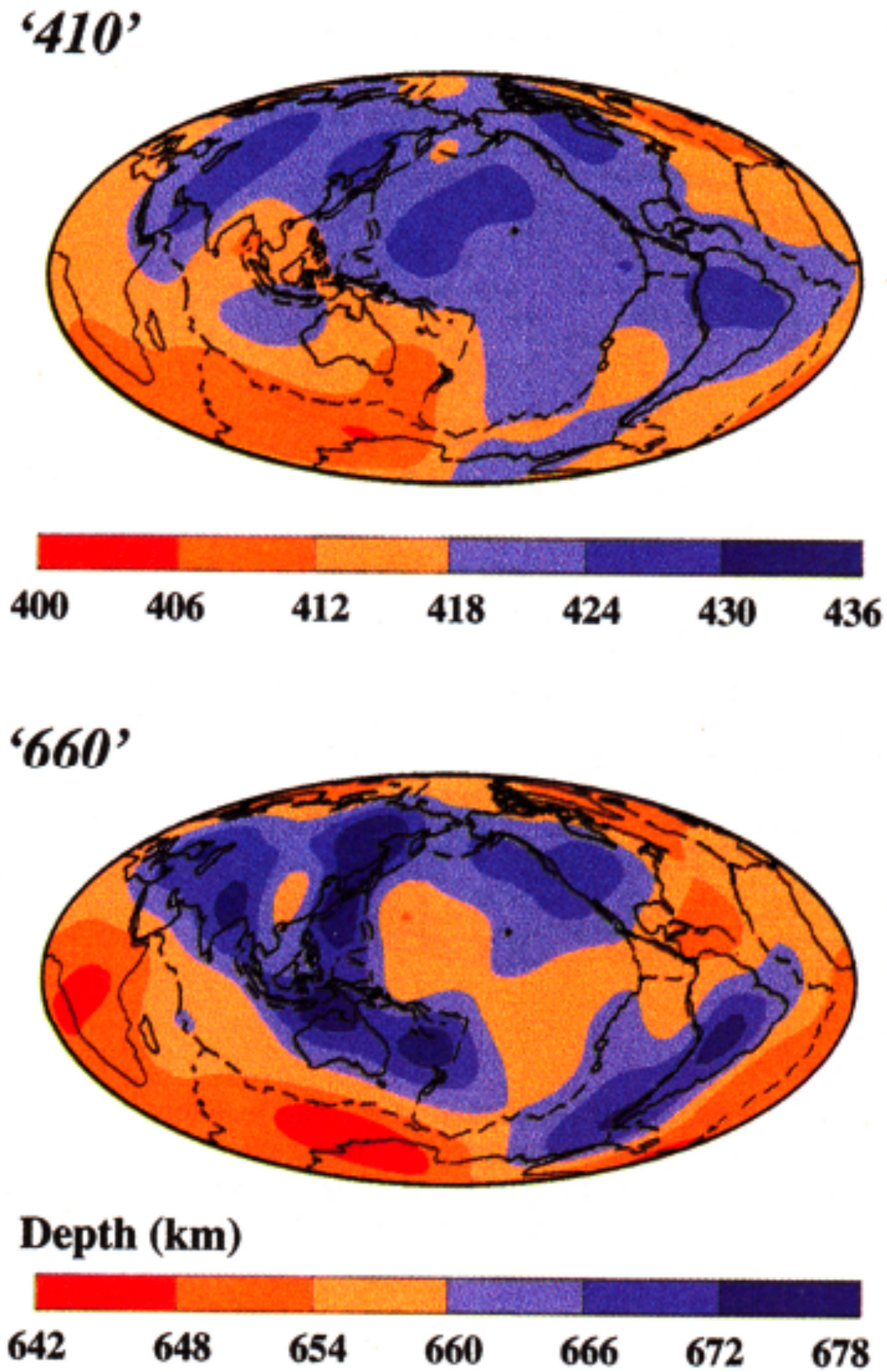


Xu et al. (2008) EPSL

Mantle Discontinuities: Topography

- Topography on "410" and "660" is significant and measurable
- Lateral variations in temperature?
- E.g. regions influenced by subduction should be colder
- Topography on 660 correlates reasonably well with subduction and Clapeyron slope
- Topography on 410 doesn't
- Why?

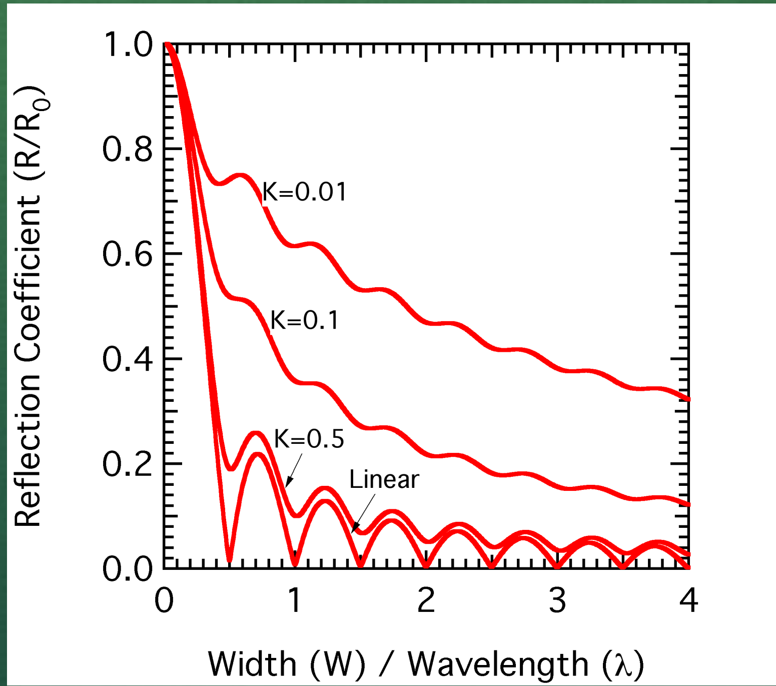
Flanagan & Shearer (1998) JGR



Mantle Discontinuities: Width

- Waves can reflect or convert at discontinuities
- Amplitude depends on
  - Contrast in velocity
  - Ratio of width to wavelength
- Width is controlled by thermodynamics: Increases with decreasing partition coefficient K
- Wavelength can be chosen by the seismologist by filtering
- Variation of amplitude with frequency (wavelength) can constrain width
- Typical wavelength

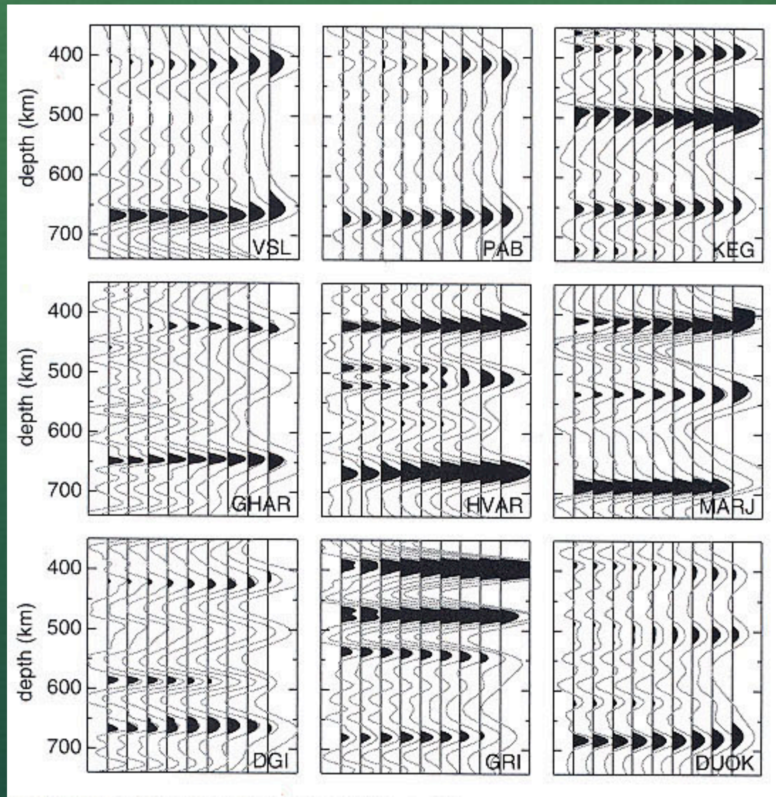
$$\lambda = 5\ \mathrm{km}\left(\frac{V_S}{5\ \mathrm{km\ s^{-1}}}\right)\left(\frac{1\ \mathrm{Hz}}{f}\right)$$



Stixrude (1997) JGR

Mantle Discontinuities: Width

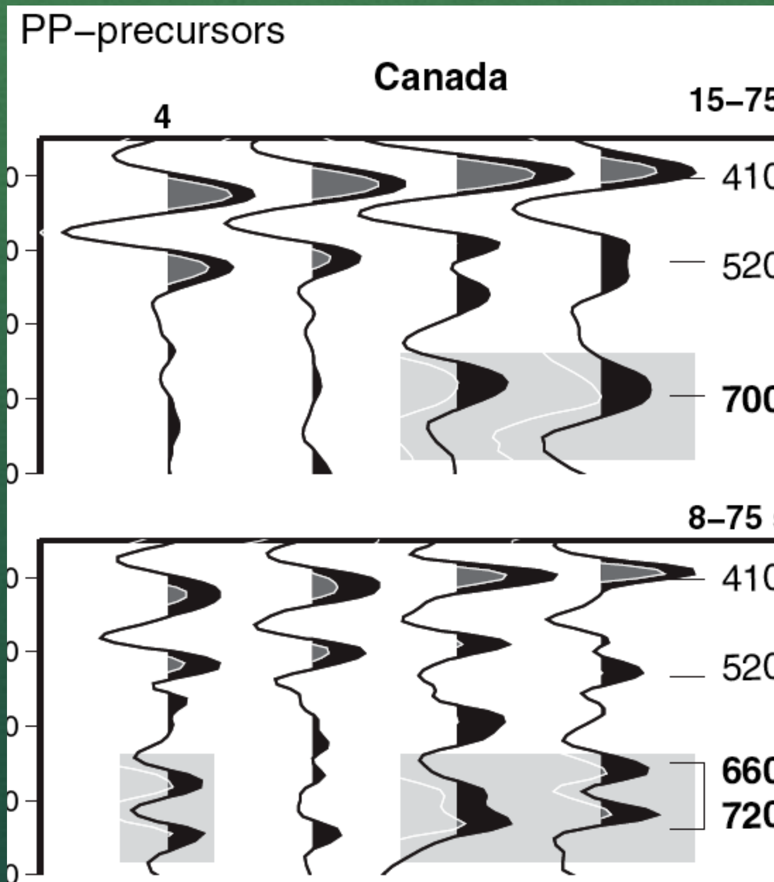
- In most parts of the mantle, the width of the 410 agrees with our simple model
- But, find that 410 is very wide in some places
- Why?
- Interpretation: Water
- Water is strongly partitioned between olivine and wadsleyite
- Strong partitioning leads to wide phase loops and broad discontinuities



Van der Meijde et al. (2003) Science

Mantle Discontinuities: Complexity

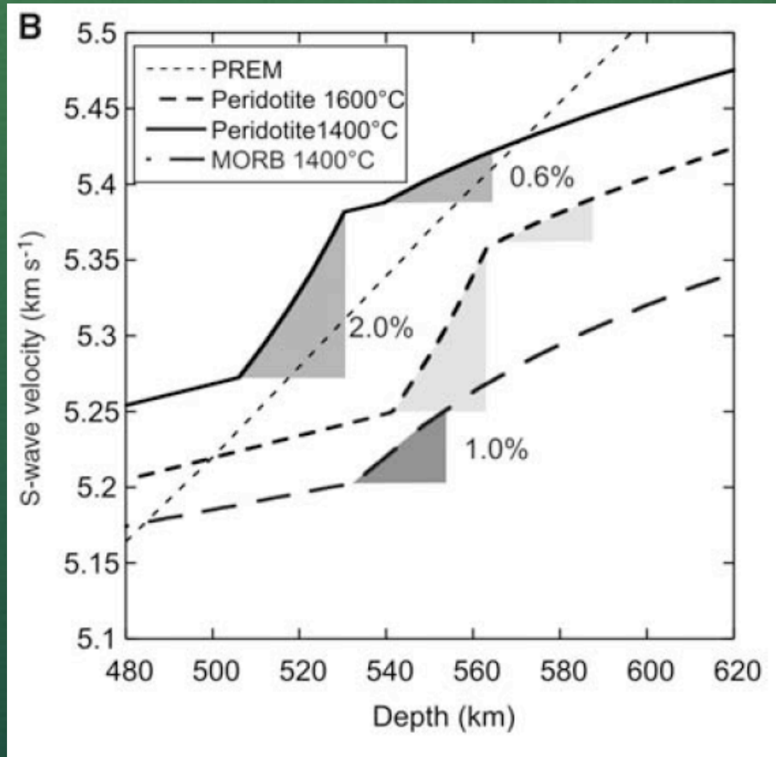
- Find 520 km discontinuity in many places, but not everywhere
- Often "split" into two discontinuities
- Why?
- Robustness
  - Number stations and earthquakes
  - Topography on boundary



Deuss et al. (2006) Science

Mantle Discontinuities: Complexity

- Wadsleyite to Ringwoodite almost certainly involved
- Exsolution of $CaSiO_3$ perovksite from garnet
- Potential probe of mantle composition

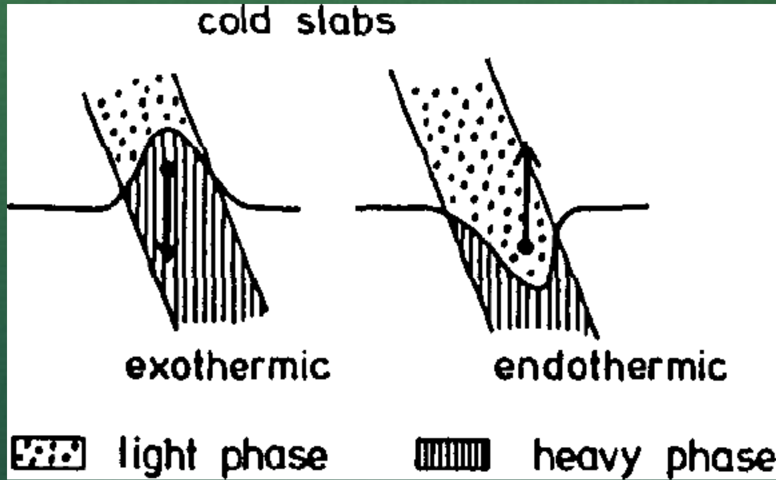


Saikia et al. (2008) Science

Influence on Dynamics?

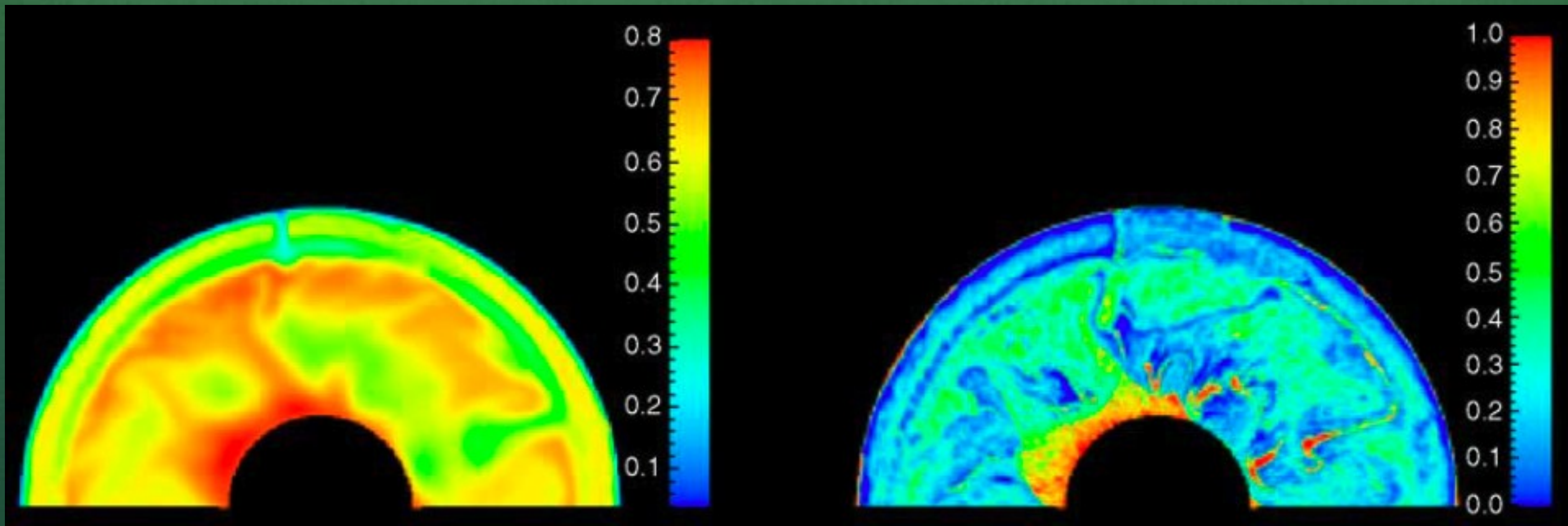
Influence on Dynamics

- Phase transitions should influence dynamics
- Negative Clapeyron slope is stabilizing, i.e. tends to retard convection
- Positive Clapeyron slope is de-stabilizing, i.e. tends to enhance convection



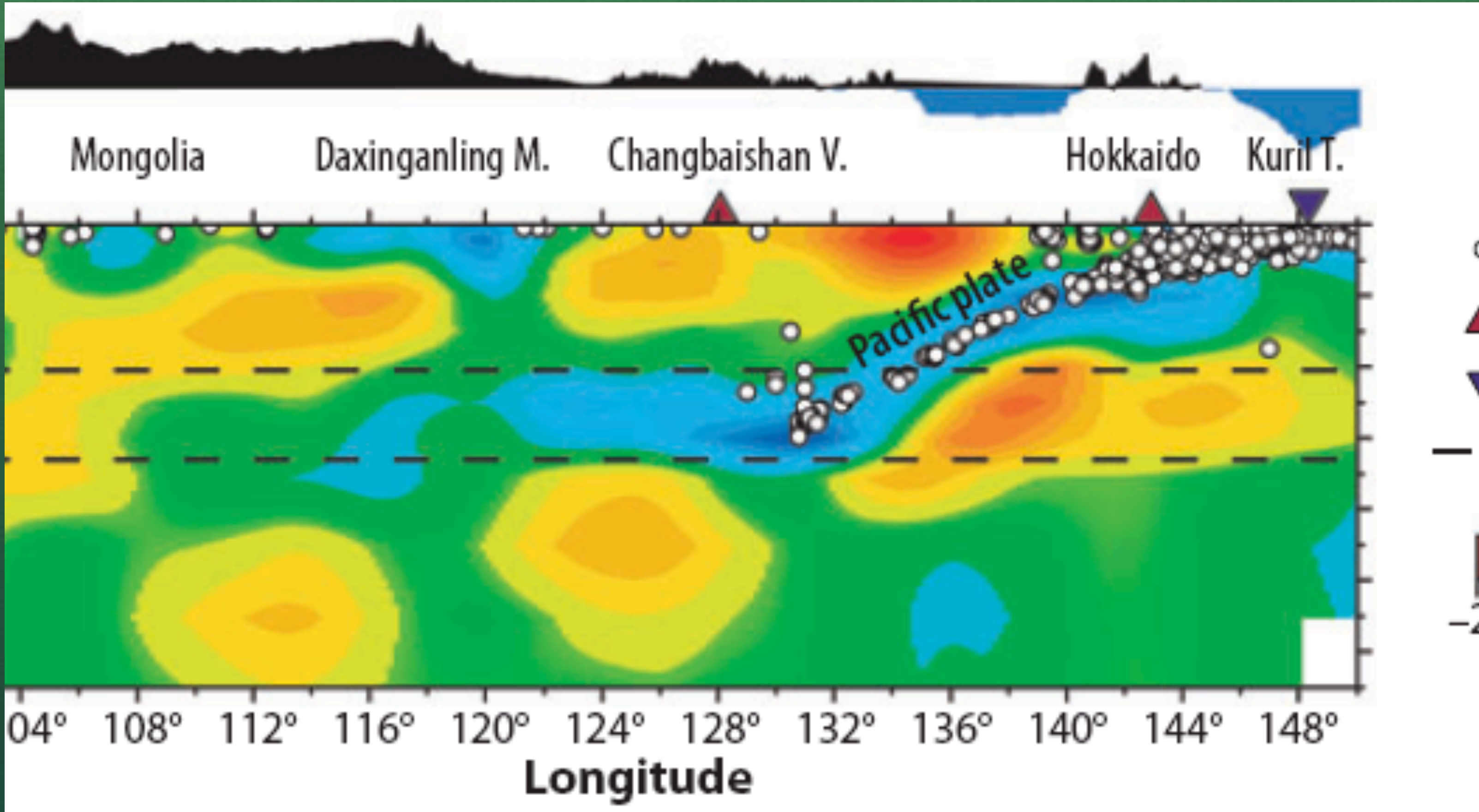
Christensen (2005) AREPS

Influence on Dynamics



Nakagawa & Buffett (2005) EPSL

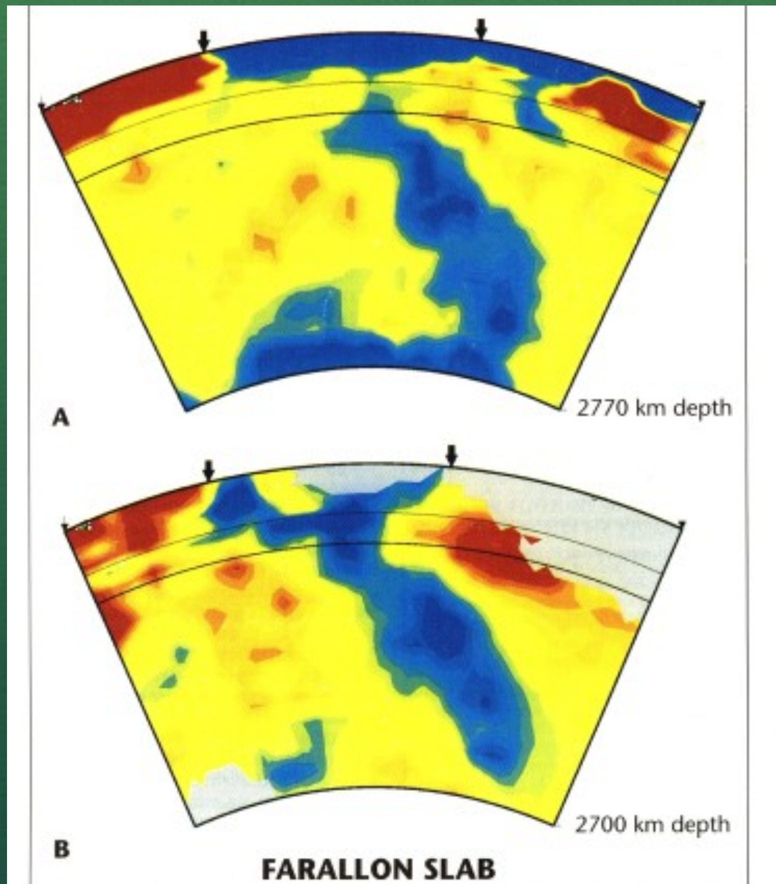
Influence on Dynamics



Fukao et al.. (2009) AREPS

Influence on Dynamics

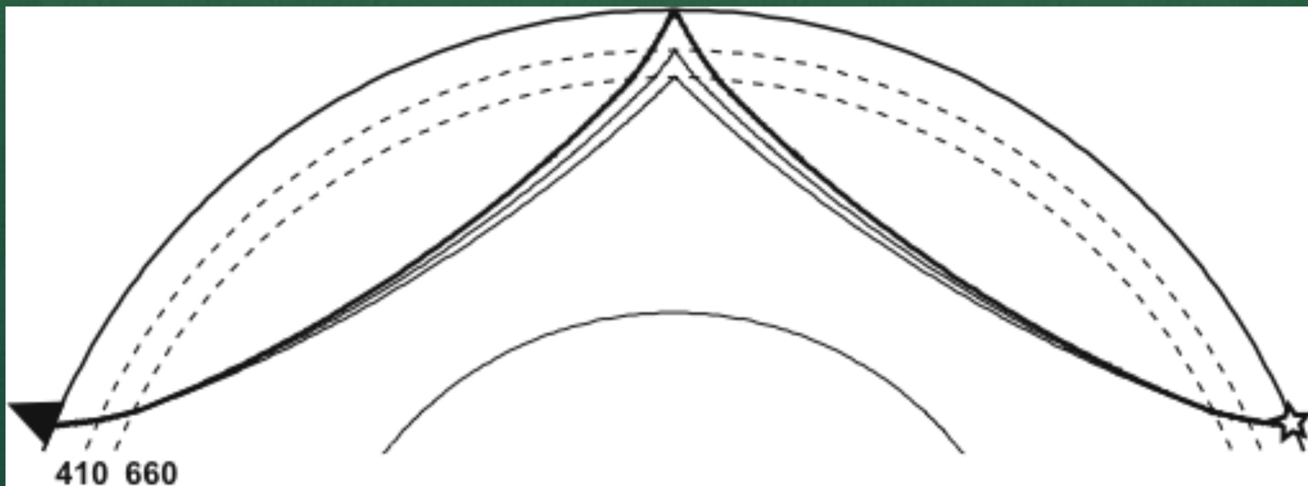
- In many places subducting slabs appear to penetrate to the core-mantle boundary
- Farallon slab imaged with S- and P-waves via seismic tomography
- Others pond in the transition zone



Grand et al. (1999) GeoTimes

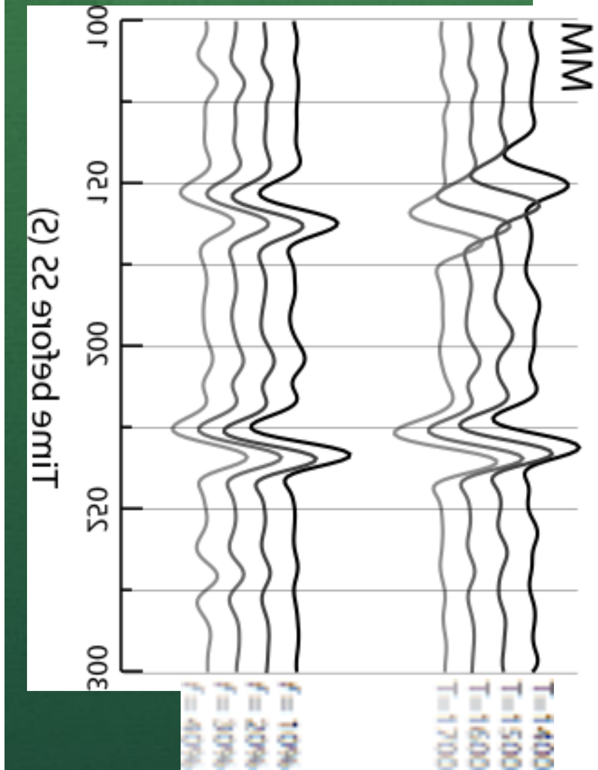
Transition Zone Thermometer

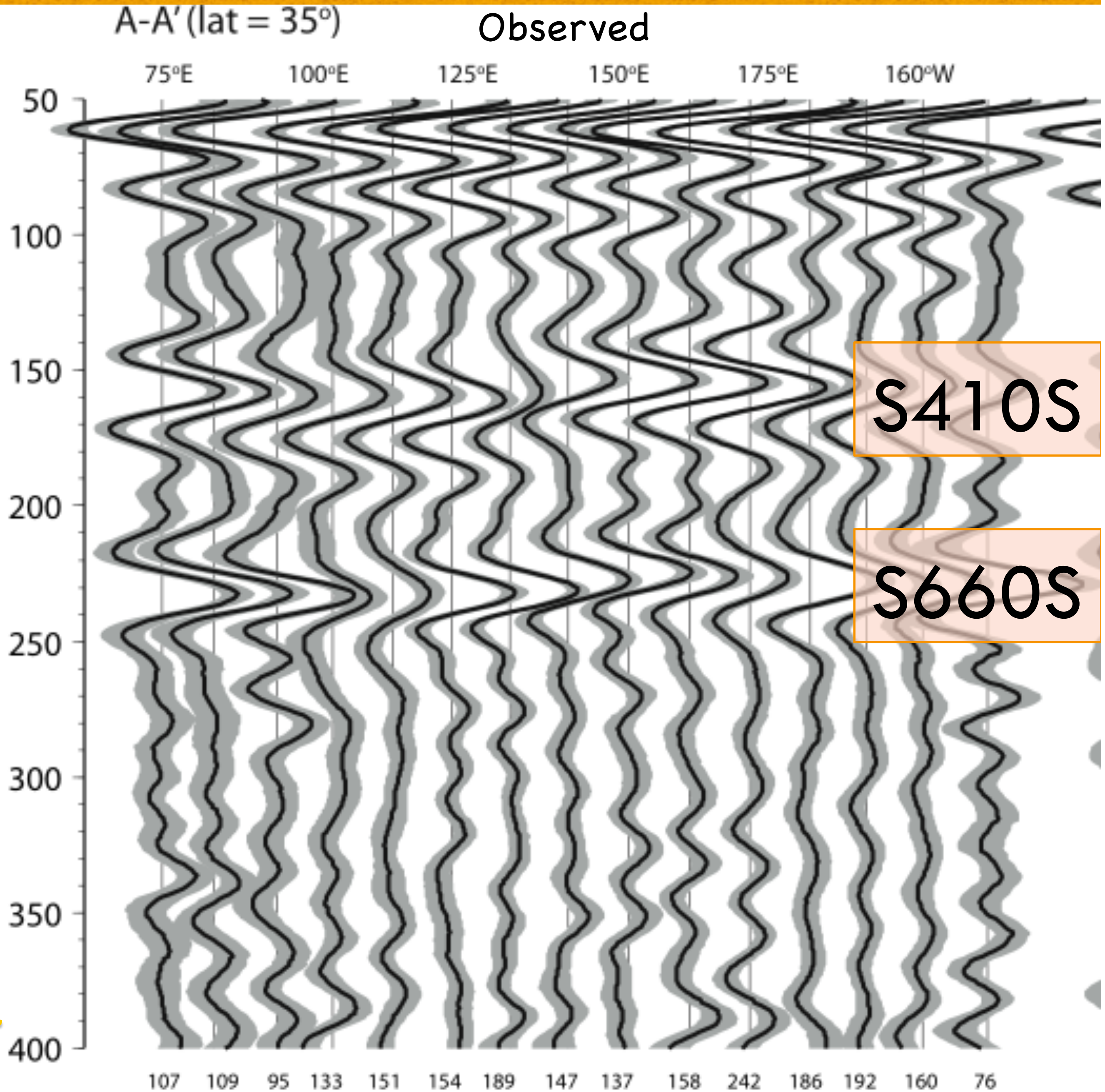
- Consider underside reflections from 410 km and 660 km seismic discontinuities (SdS)
- Difference in arrival times is sensitive only to temperature
- Match to mineralogical model



Transition Zone Thermometer

Computed from MM model via ray-tracing



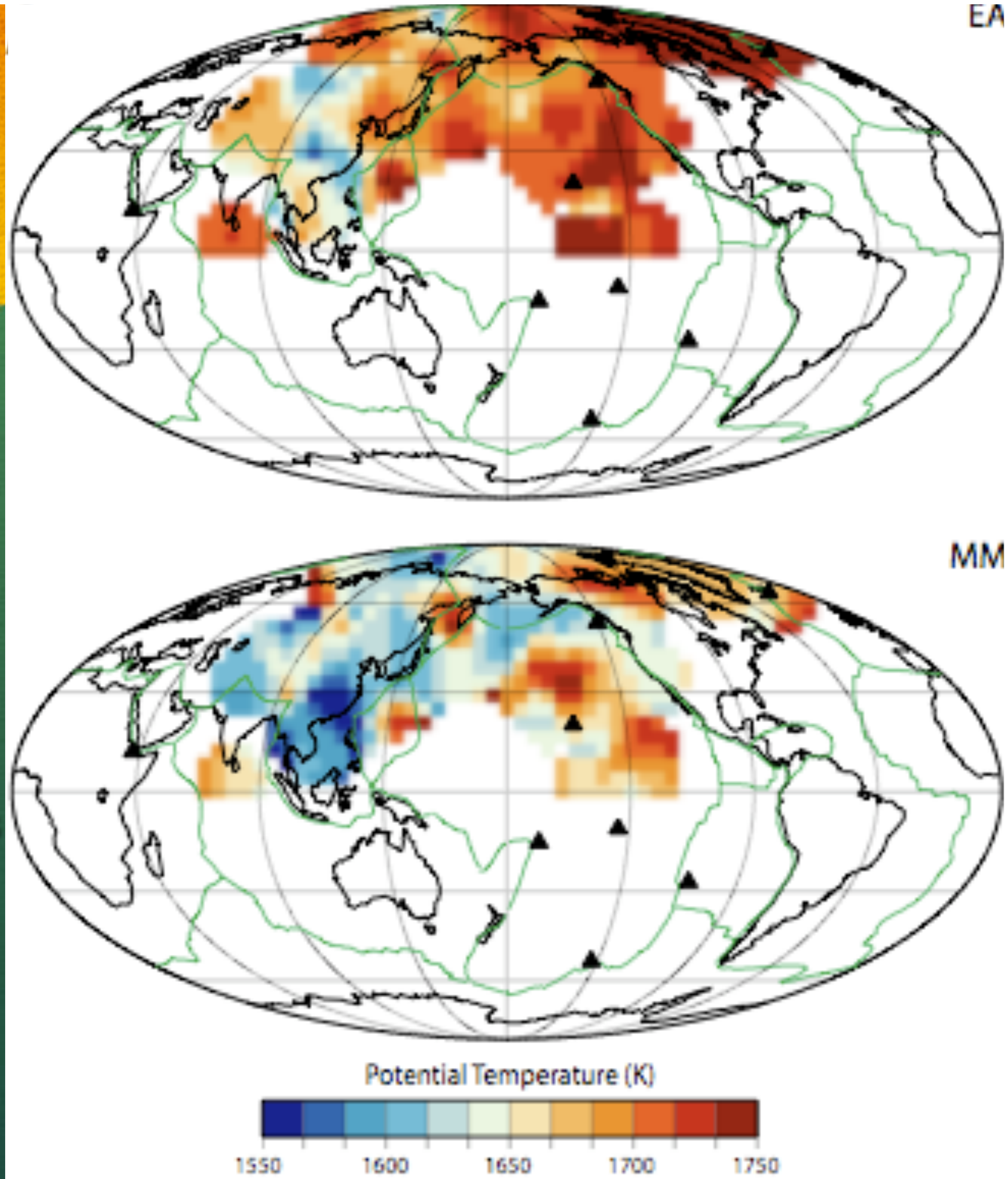


Ritsema et al. (2009) EPSL

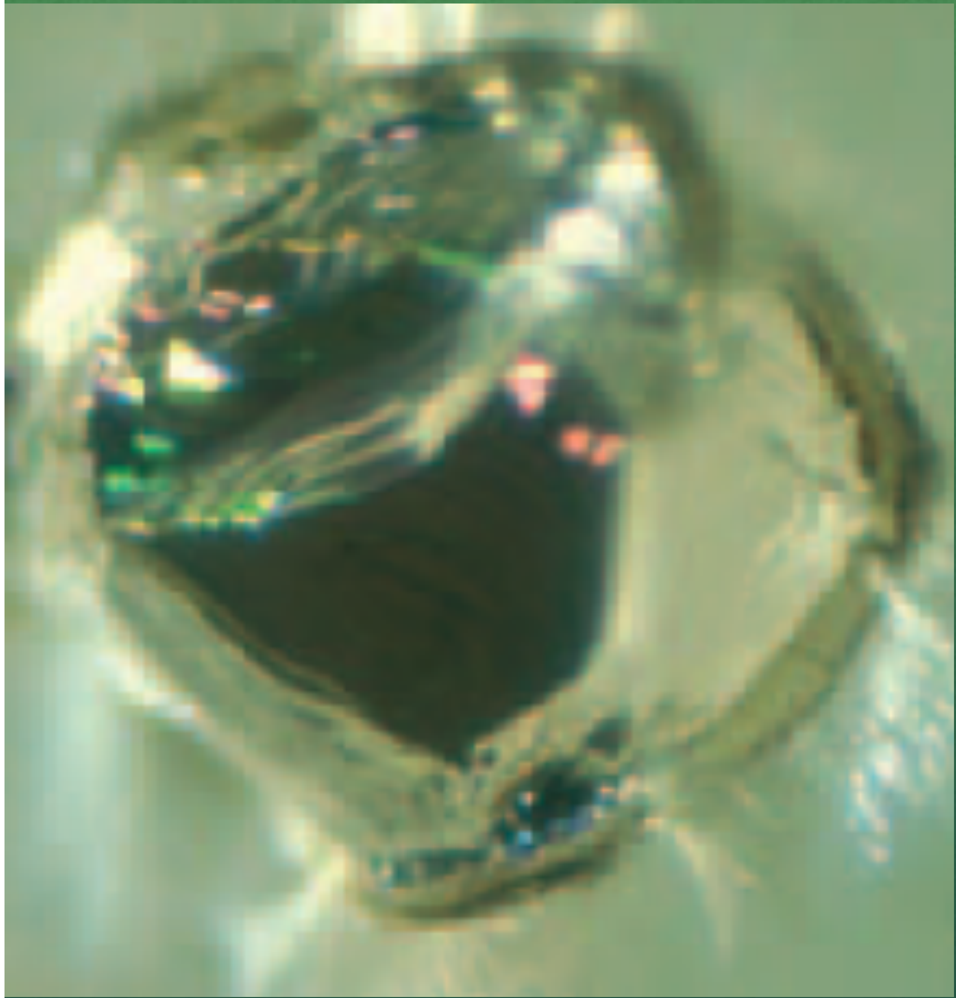
Transition Zone Thermometer

- Examine in terms of lateral variations in *potential* temperature
- Equivalent to lateral variations in entropy
- MM Results are sensible
- Mean value near that required for MORB genesis
- Magnitude of lateral variations consistent with tomographic models and dynamical simulations

Ritsema et al. (2009) EPSL

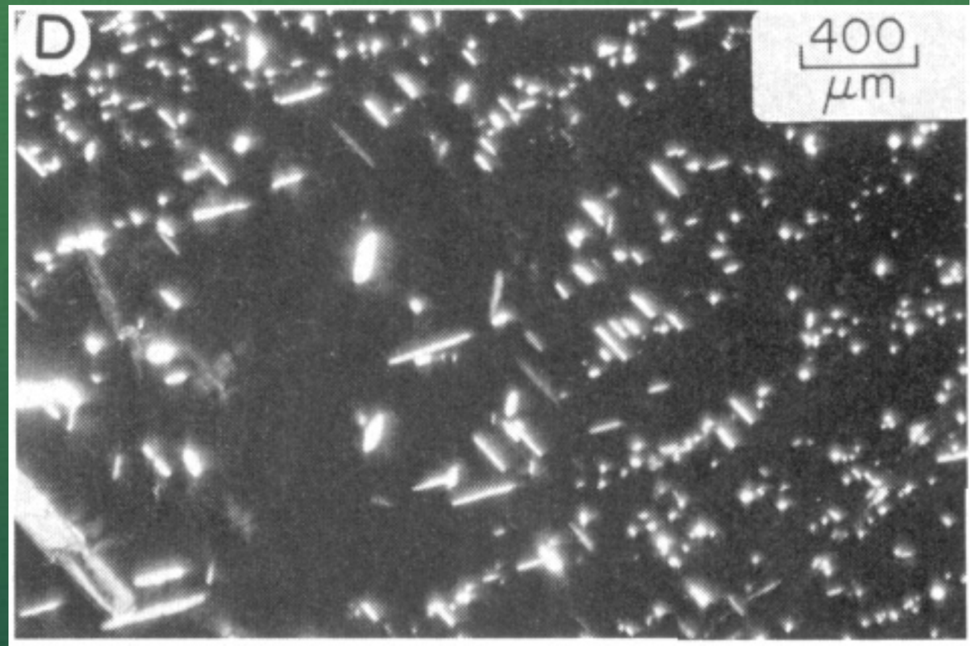


Samples of the Transition Zone?



Jeffrey W. Harris (2005)

Ferropericlase inclusion in diamond Sao Luiz alluvial deposit, Brazil



Haggerty and Sautter (1990)

Cpx exsolution lamellae from garnet, Jagersfontein Kimberlite, South Africa

Samples of Transition Zone?

- Komatiite lavas
- Archean
- High MgO
- Inferred high pressure of origin
- May come from melting that starts as deep as the uppermost lower mantle

Road Map

- Next Lecture
  - Mantle Dynamics
- Practical
  - HeFESTo