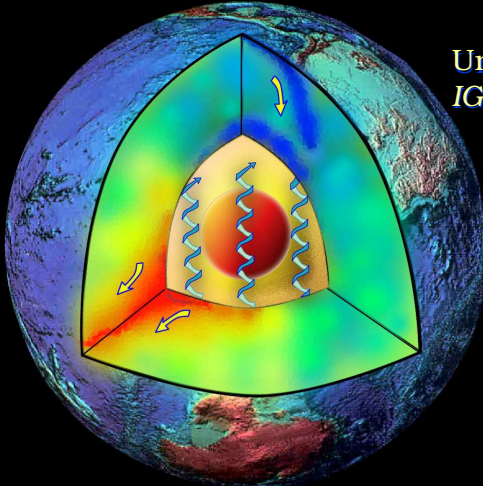





Processes at the CMB

Thorne Lay
University of California, Santa Cruz
IGPP/Earth Sciences Department



2004 Cider Workshop

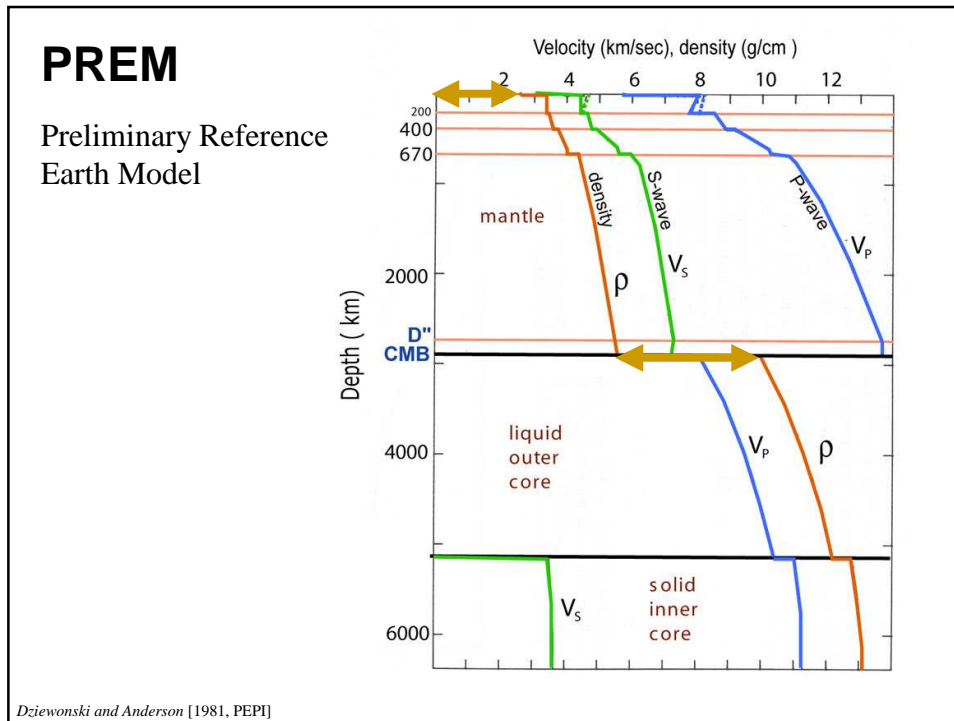
With thanks to Collaborators:
Ed Garnero, Tine Thomas, Megan Avants, Juliana Rokosky, and others



THE UNIVERSITY of LIVERPOOL

OUTLINE :

- The CMB: Earth's major internal boundary and the D'' thermo-chemical boundary layer: SEISMOLOGICAL Perspective
- General attributes of D'' structure
- Regional case studies: structural and dynamical complexity
- Sum up: Important future directions



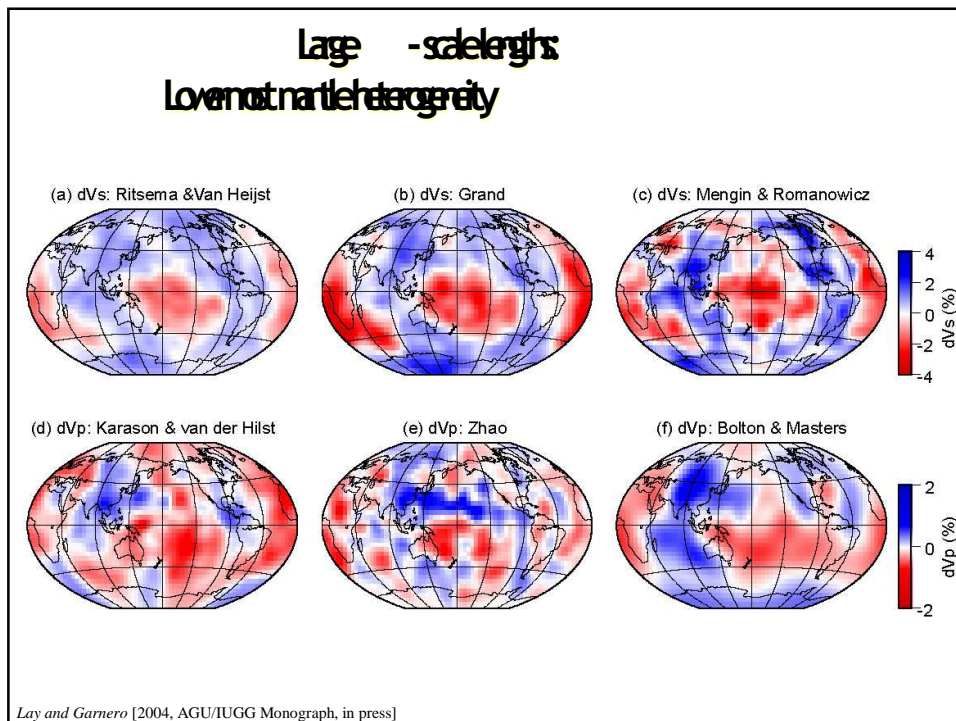
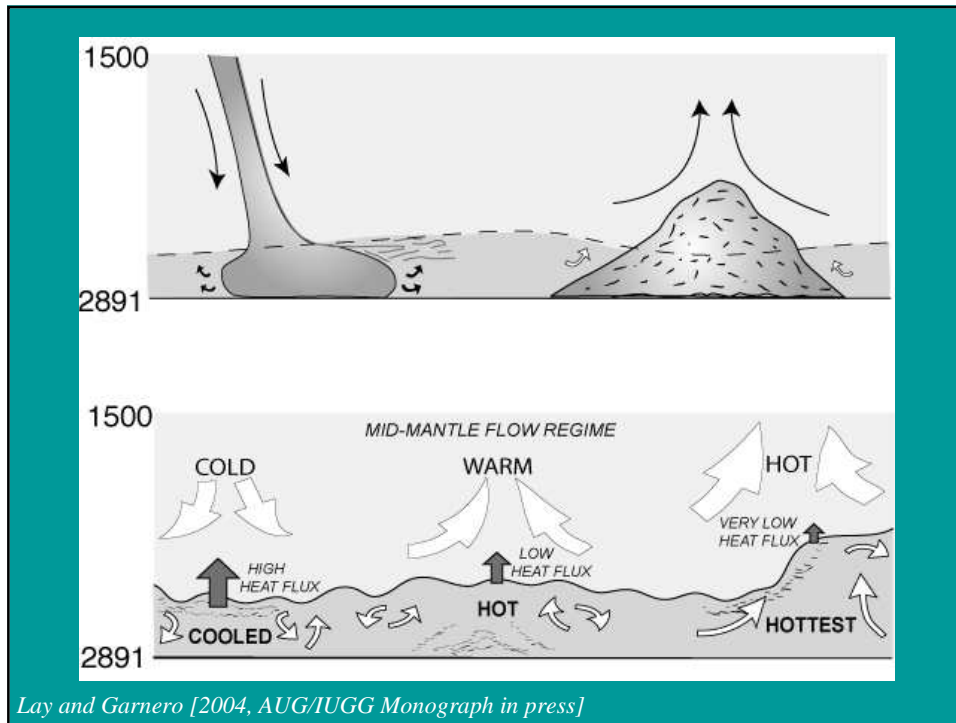
The D'' Region is likely to have a Thermal Boundary Layer (TBL) due to flux of heat from the core:

- ◆ From 2-15 TW may flux through CMB
- ◆ If there are no mid-mantle TBLs, may have 1000+° C temperature increase across TBL
- ◆ May approach eutectic melting curve in hot boundary Layer

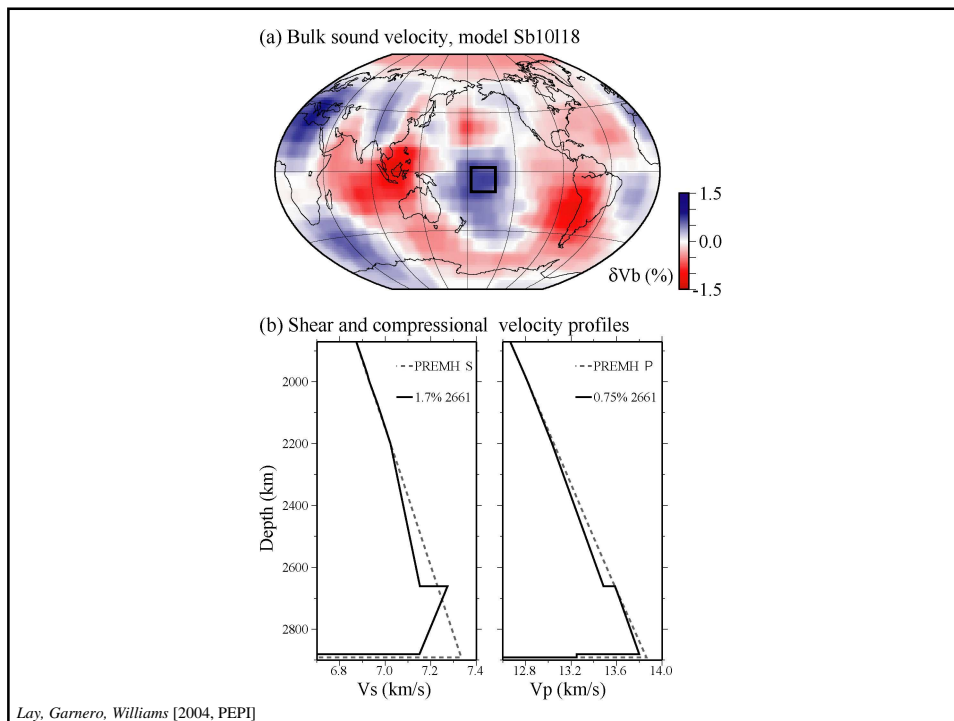
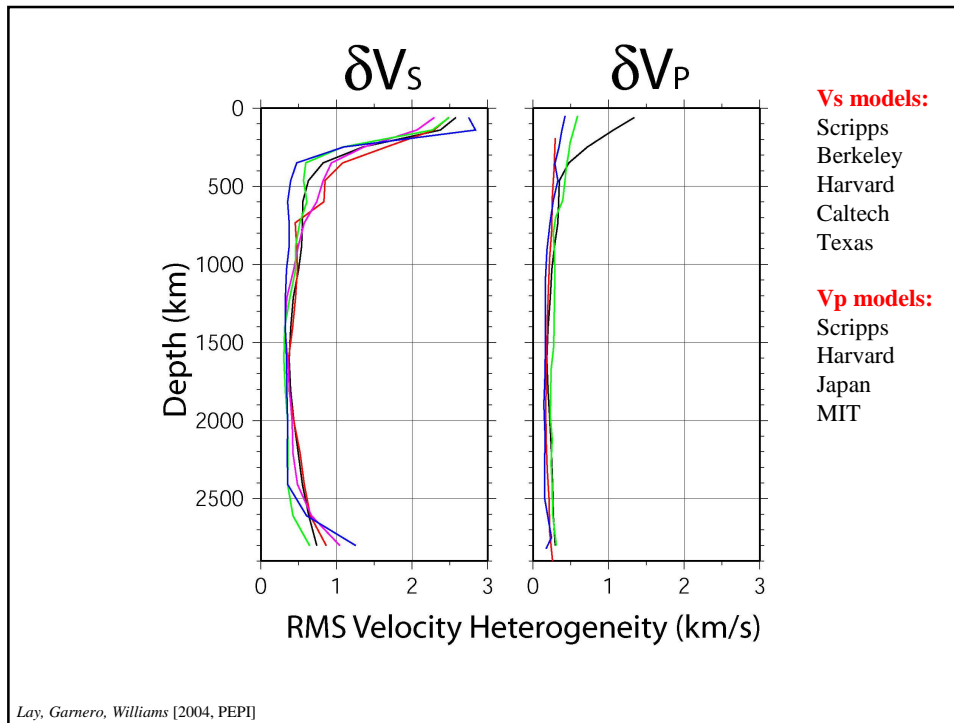
The D'' Region is likely to have Chemical Heterogeneity due to:

- ◆ Huge density/composition contrast at CMB in a chemically stratified planet
- ◆ Chemical flux into/out of core over Earth history

Lead Review: Seismology: Processes at the Core Mantle Boundary

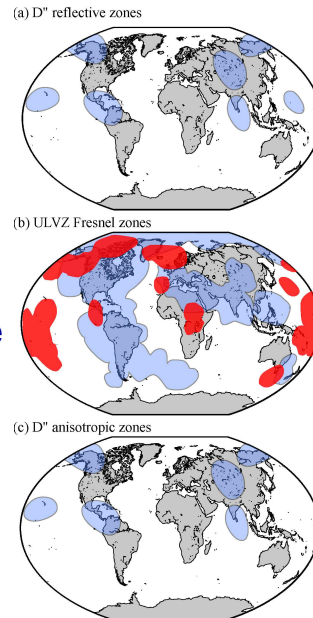


Lead Review: Seismology: Processes at the Core Mantle Boundary

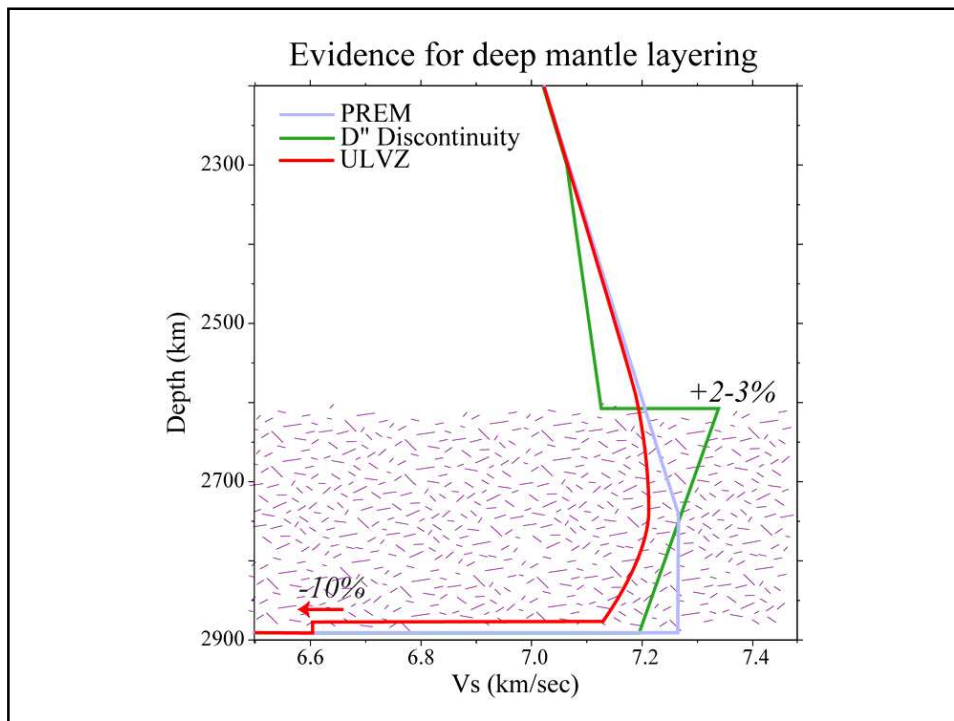


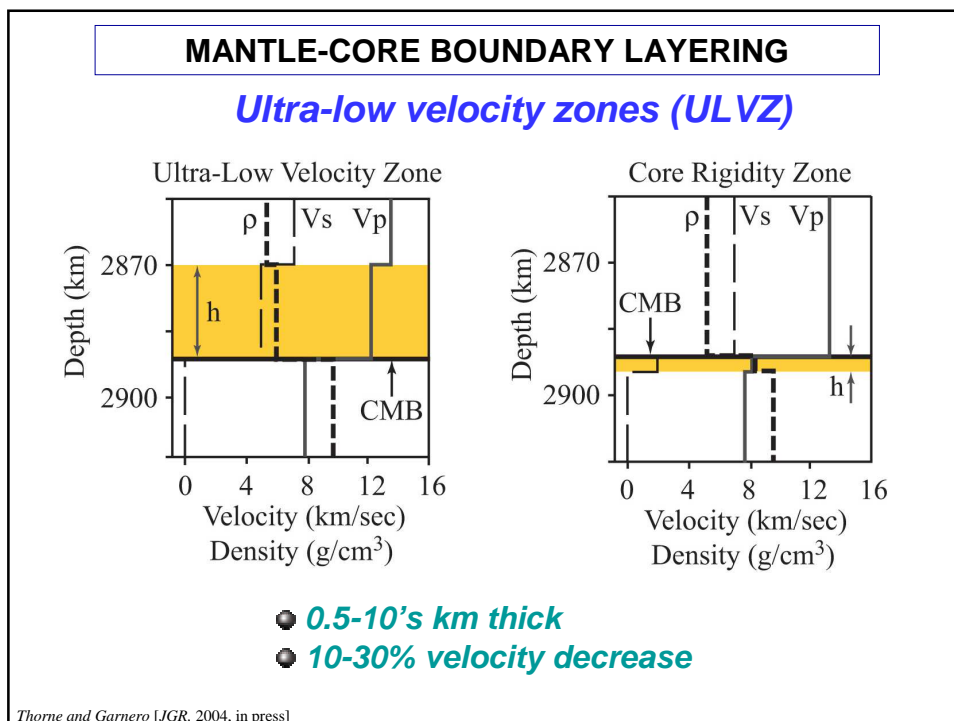
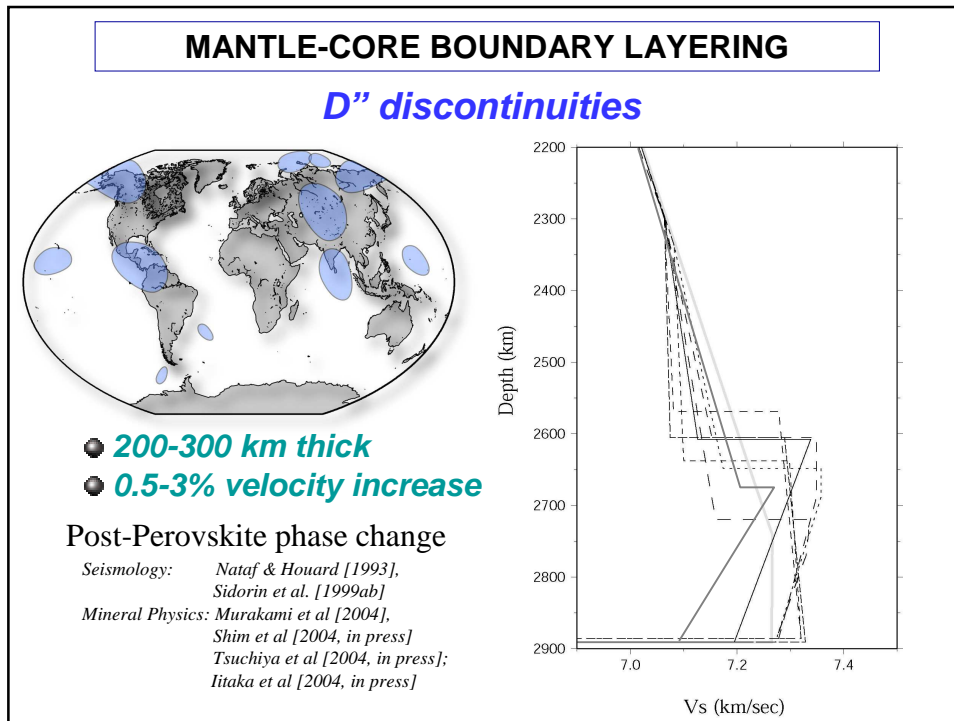
Other important deep mantle findings/analyses:

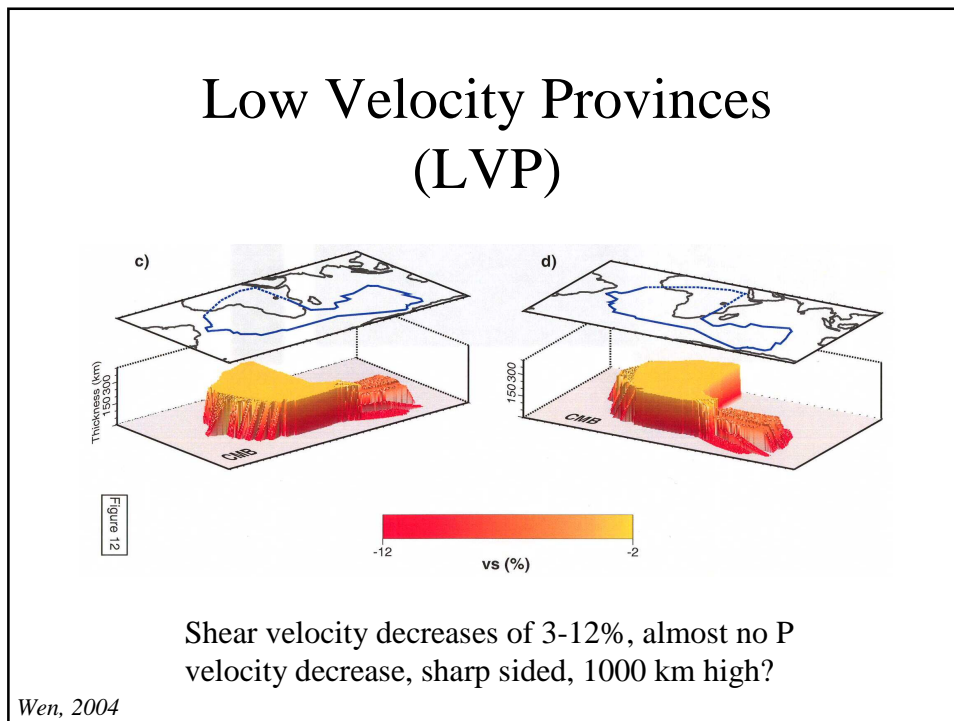
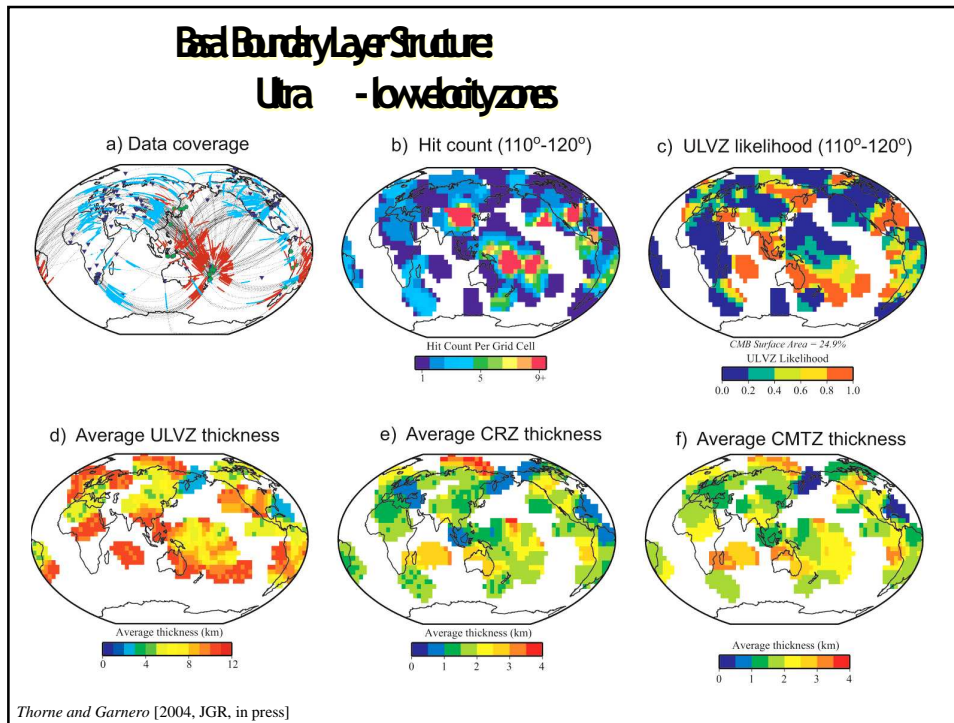
- D" discontinuity from anomalous reflections
- Ultra-low velocity zones from reflections, time and amplitude anomalies
- D" anisotropy from shear wave splitting



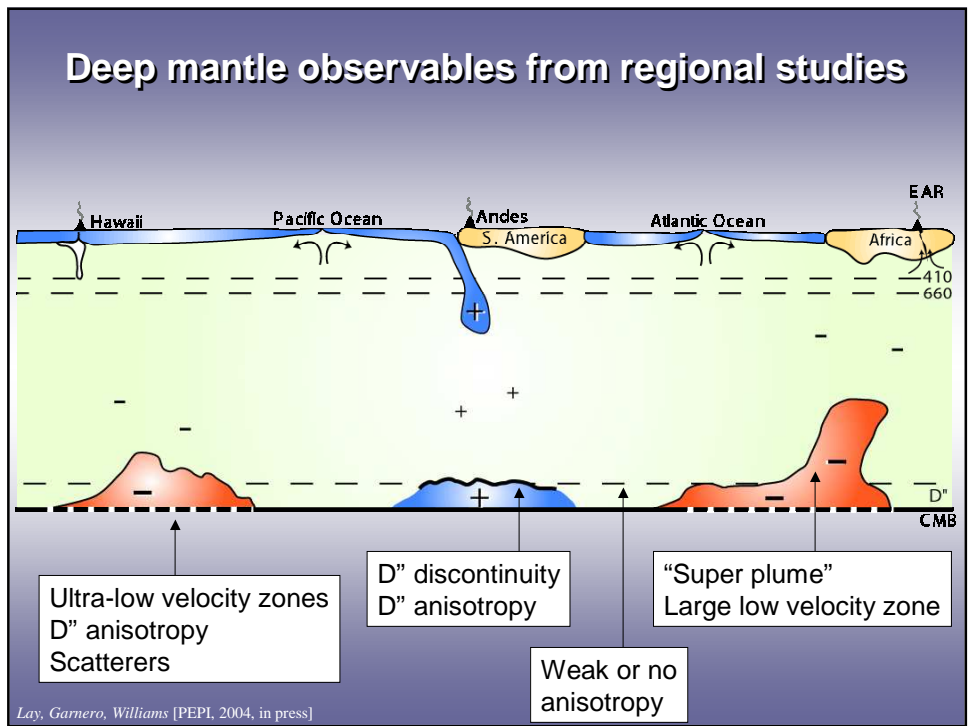
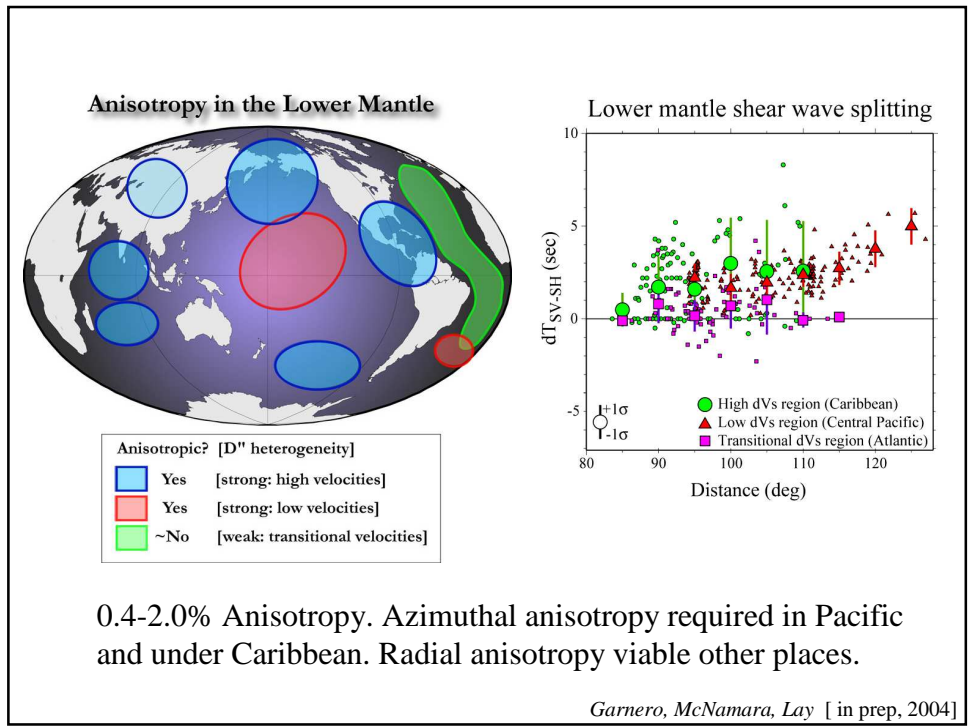
Lay, Garnero, Williams [2004, PEPI]







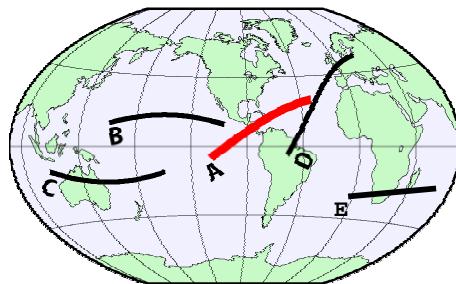
Lead Review: Seismology: Processes at the Core Mantle Boundary



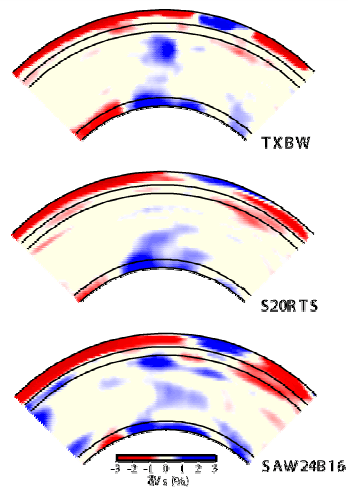
Regional Case Studies

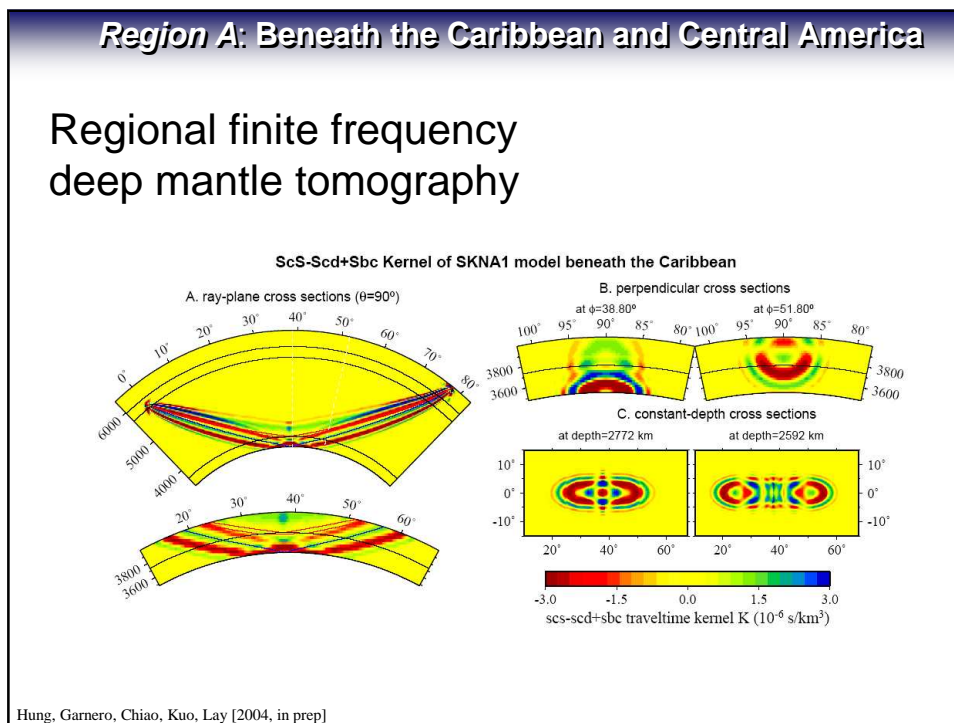
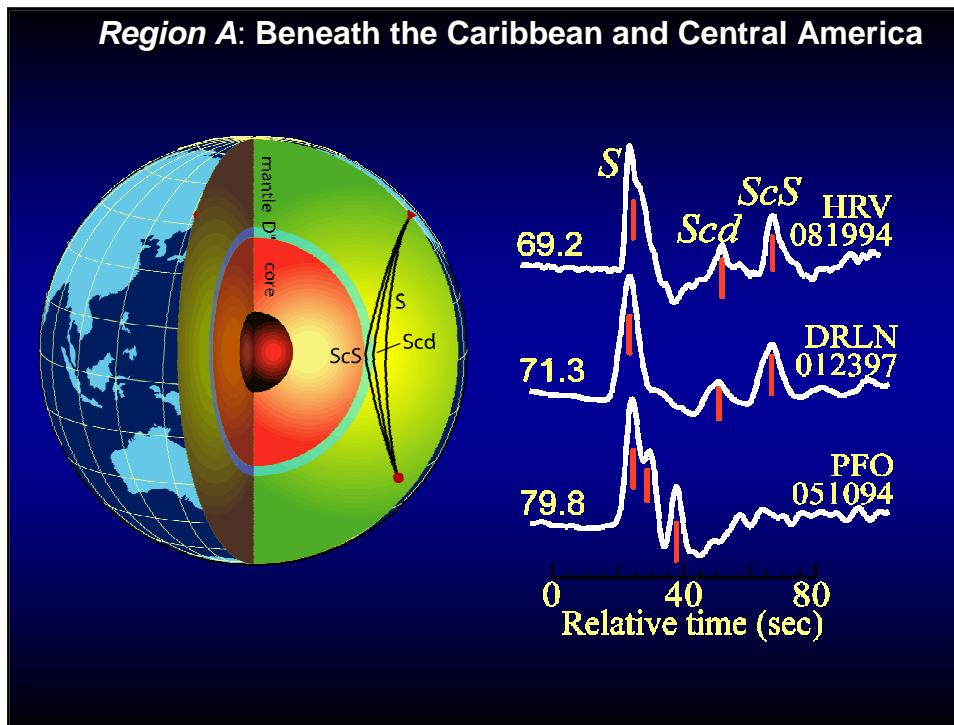
- **A:** Beneath the Caribbean/Central America
- **B:** Beneath the central Pacific
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- **D:** Beneath the central Atlantic
- **E:** Beneath South Africa, S. Atlantic, S. Indian Ocean

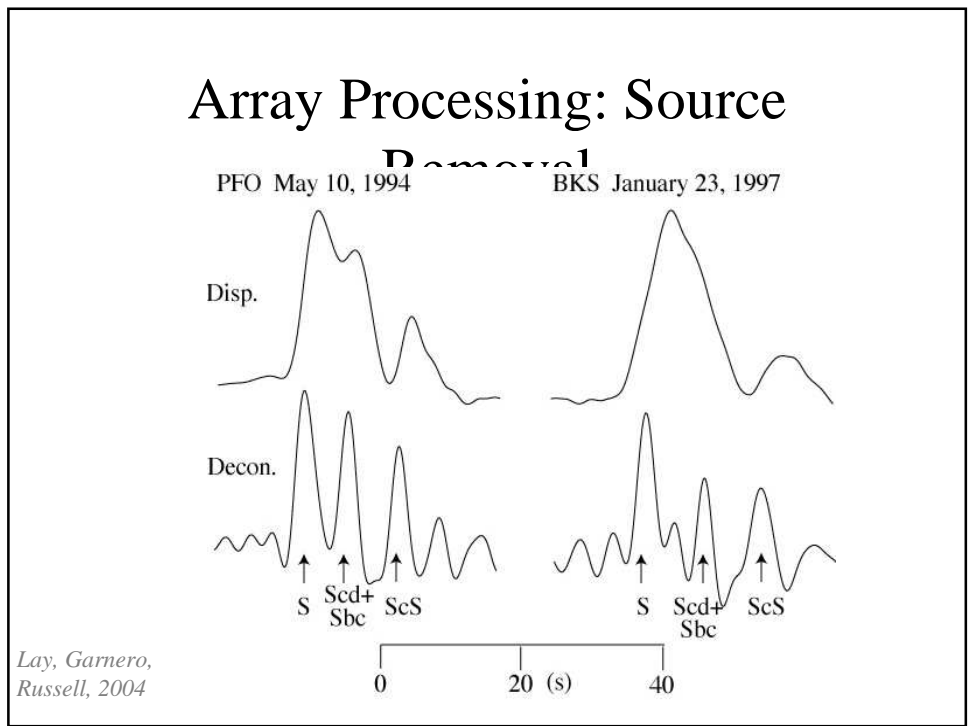
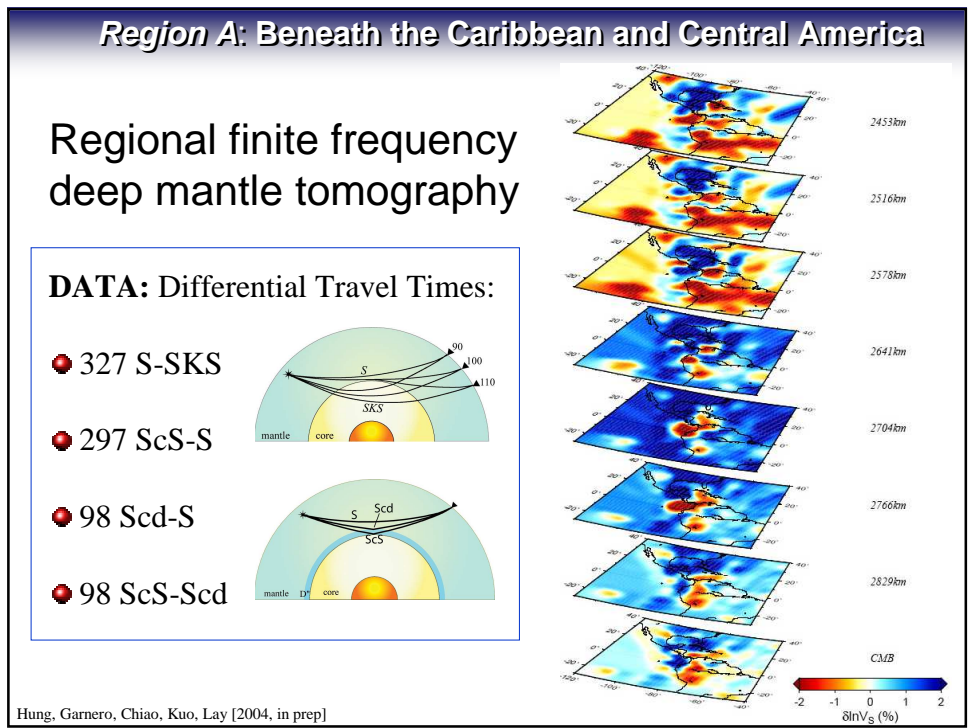
Region A: Beneath the Caribbean and Central America

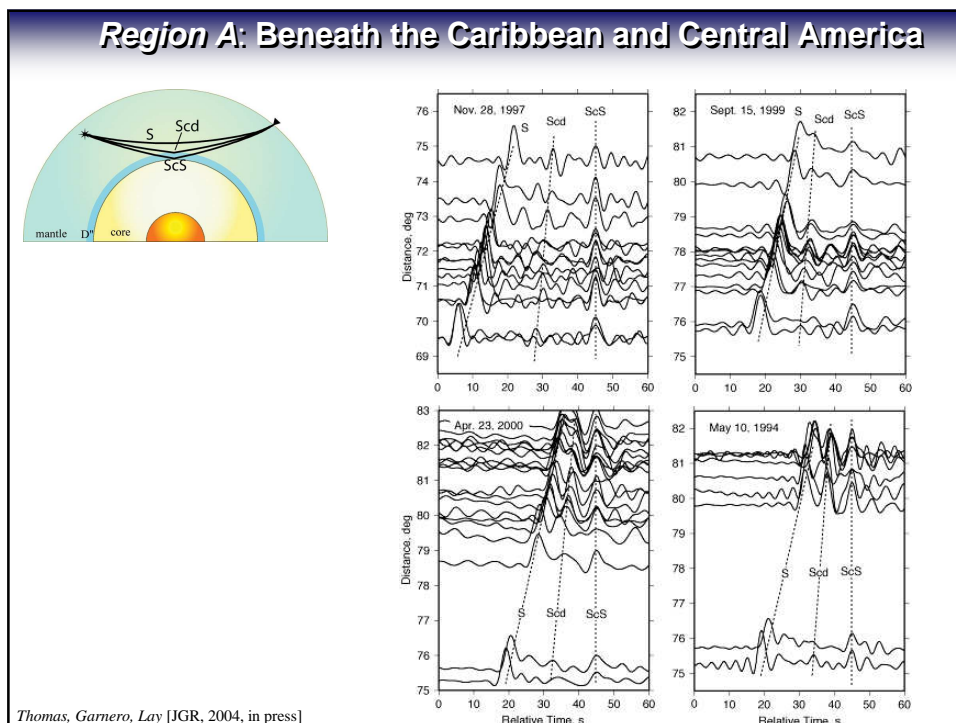
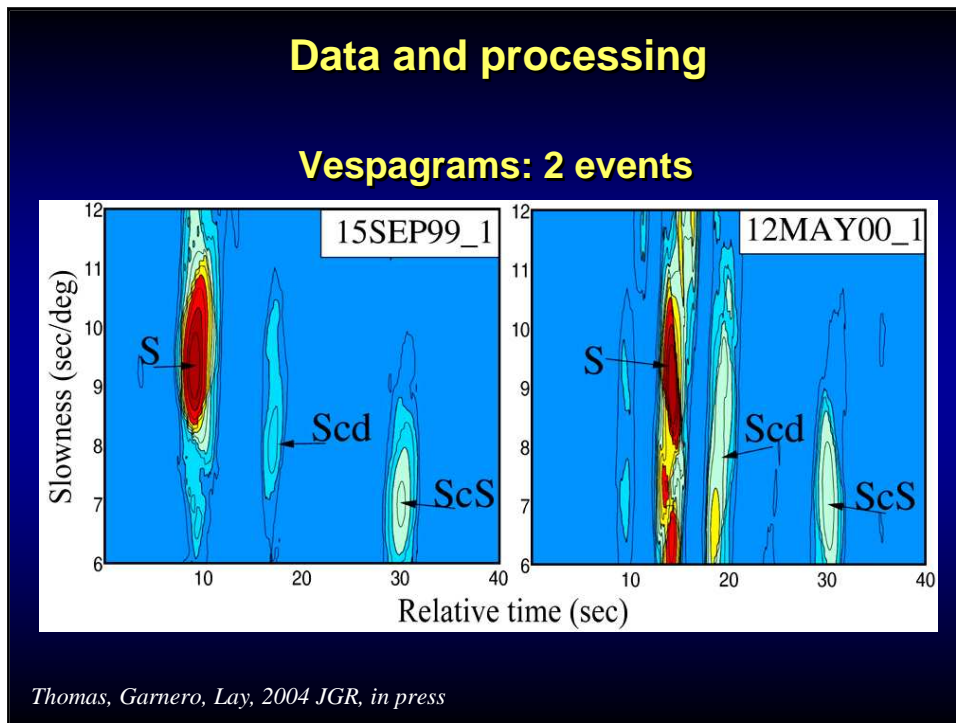


- **Strong heterogeneity**
- **D'' discontinuity**
- **D'' anisotropy**

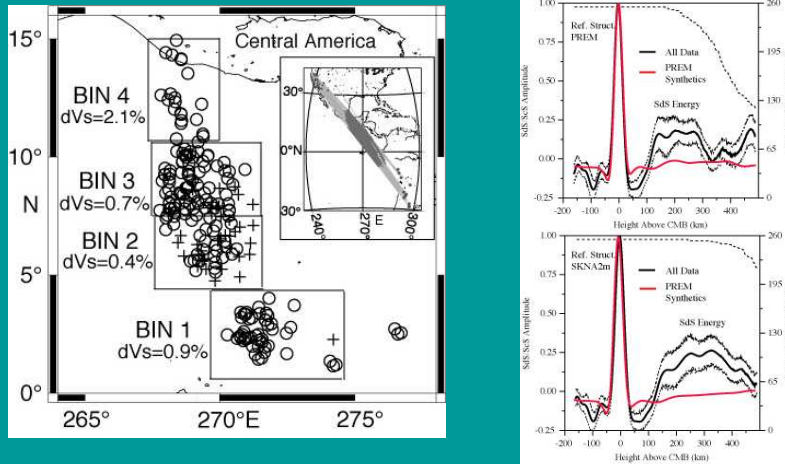






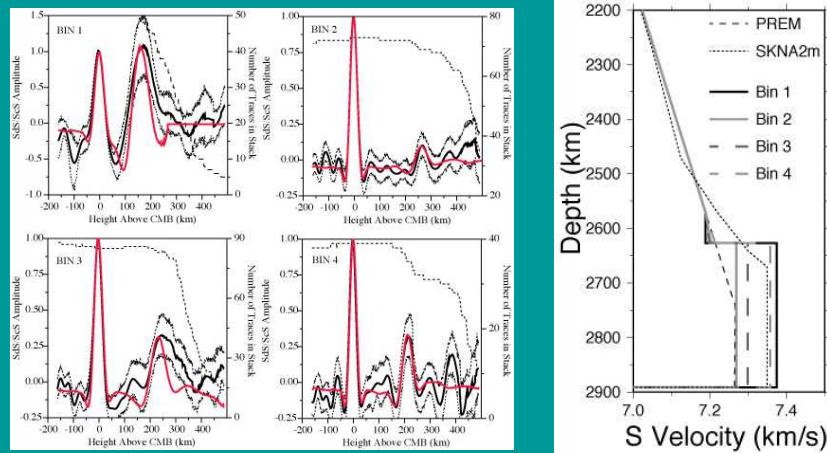


Waveform Stacking in Small Bins

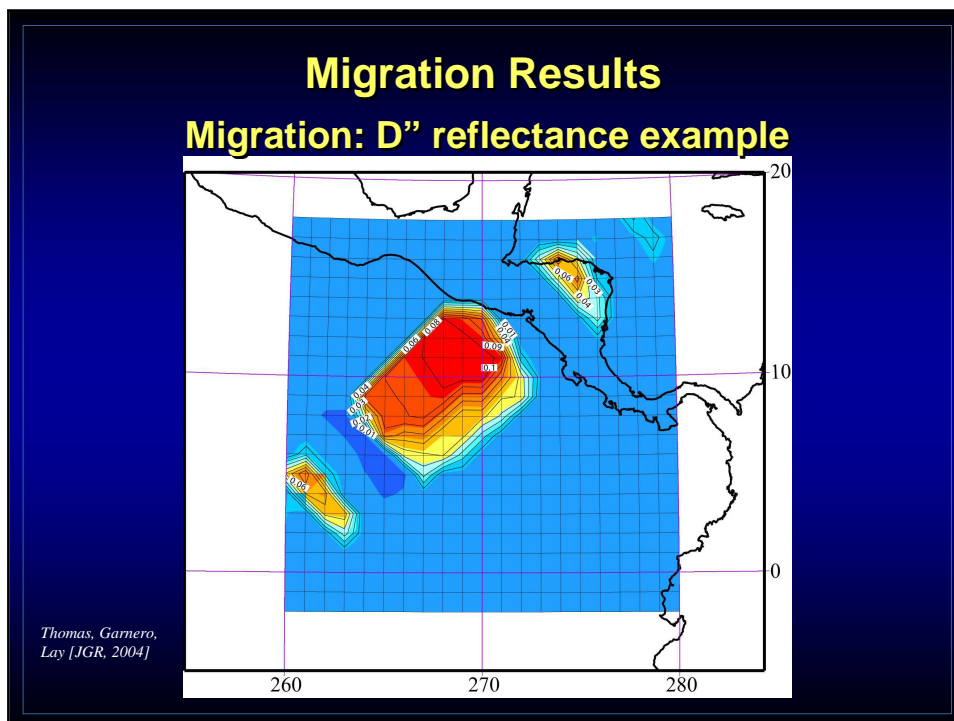
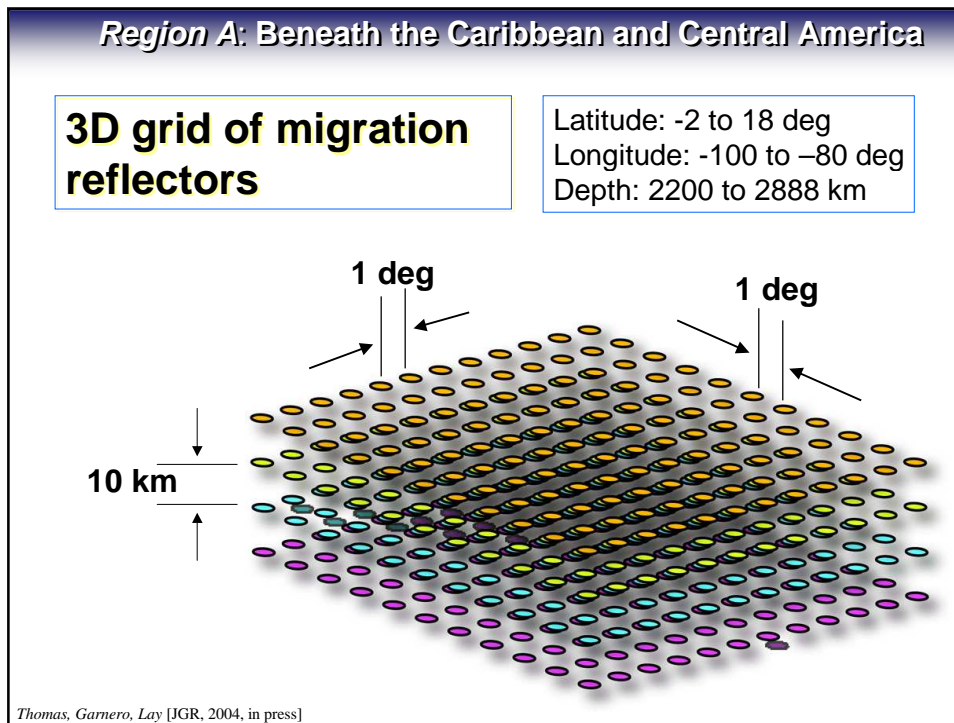


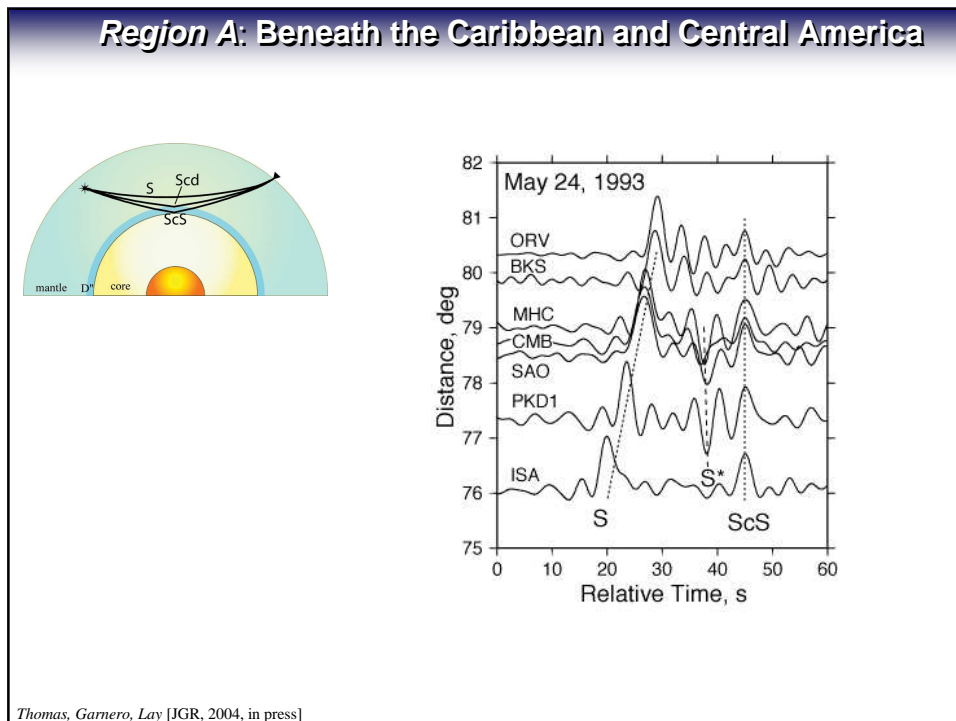
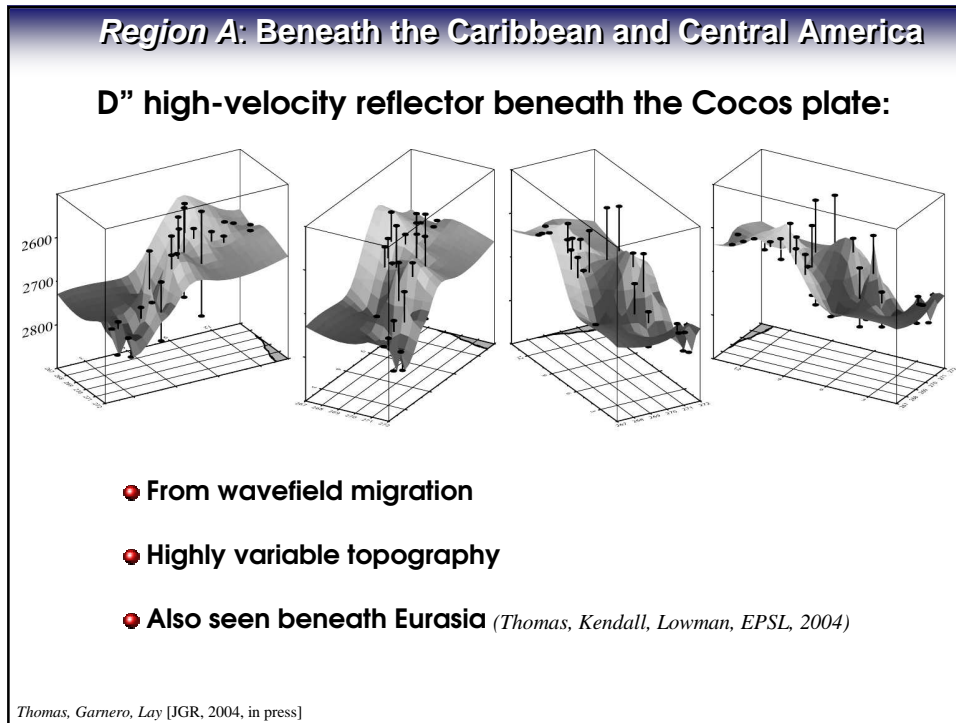
Lay, Garnero, Russell, GRL 2004

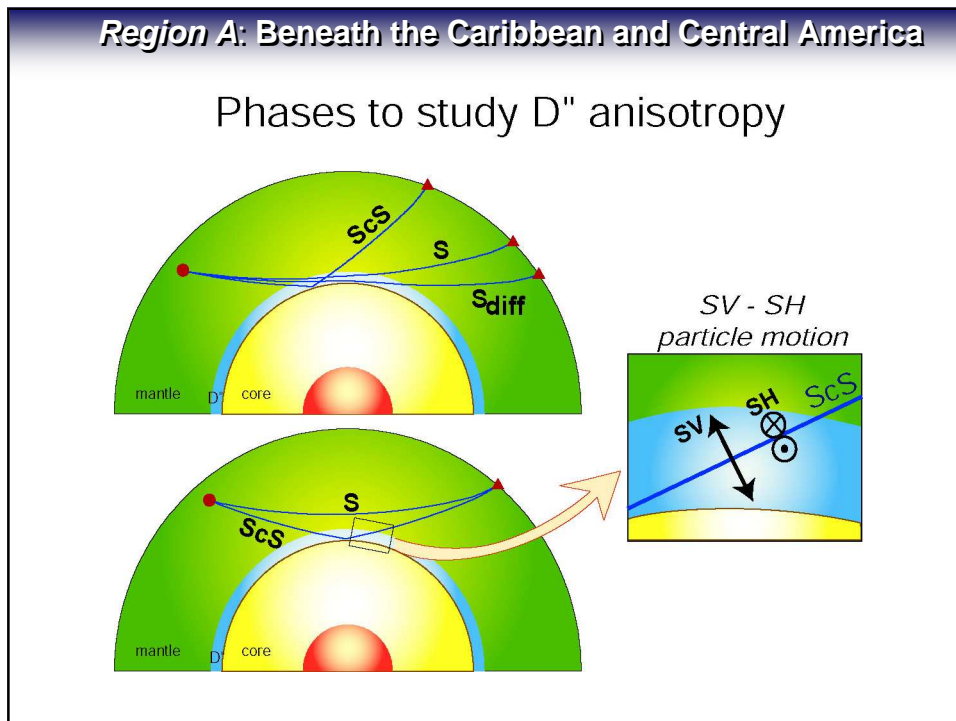
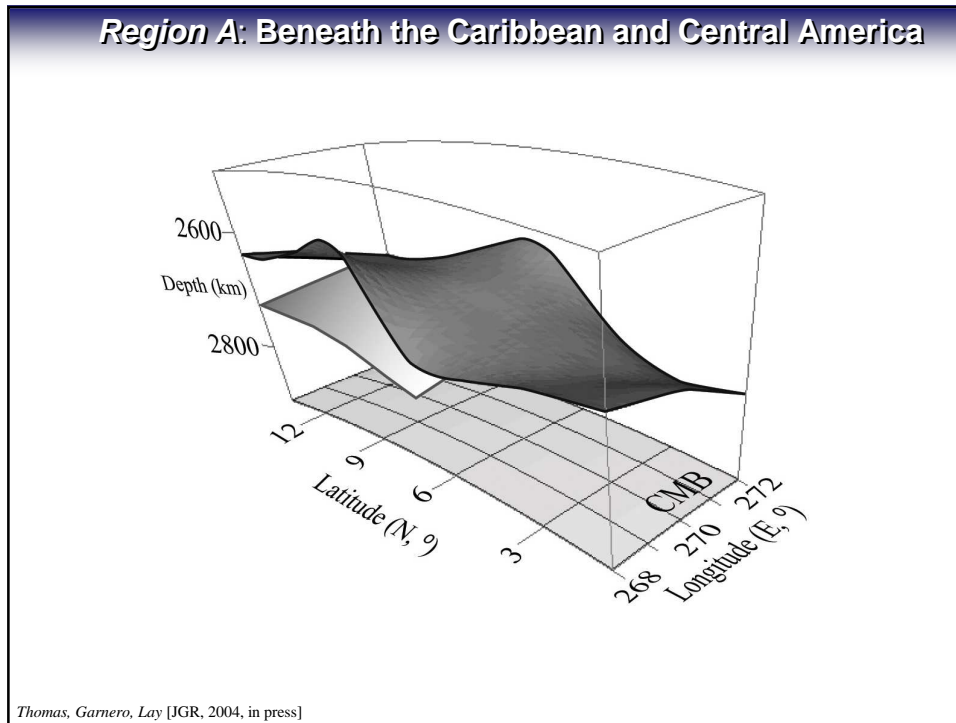
Waveform Stacking in Small Bins

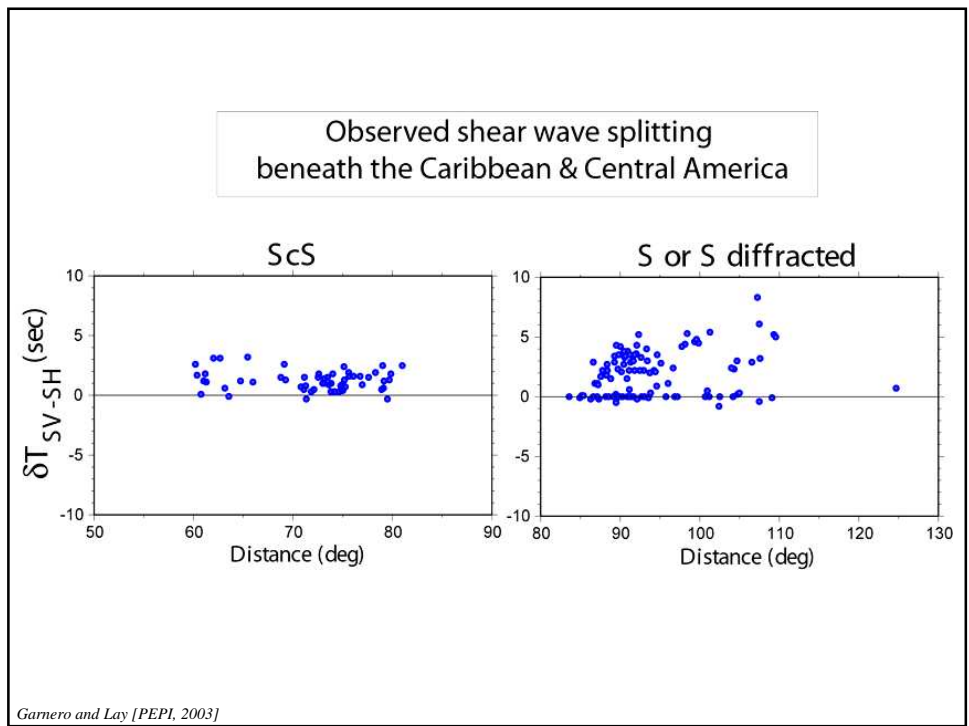
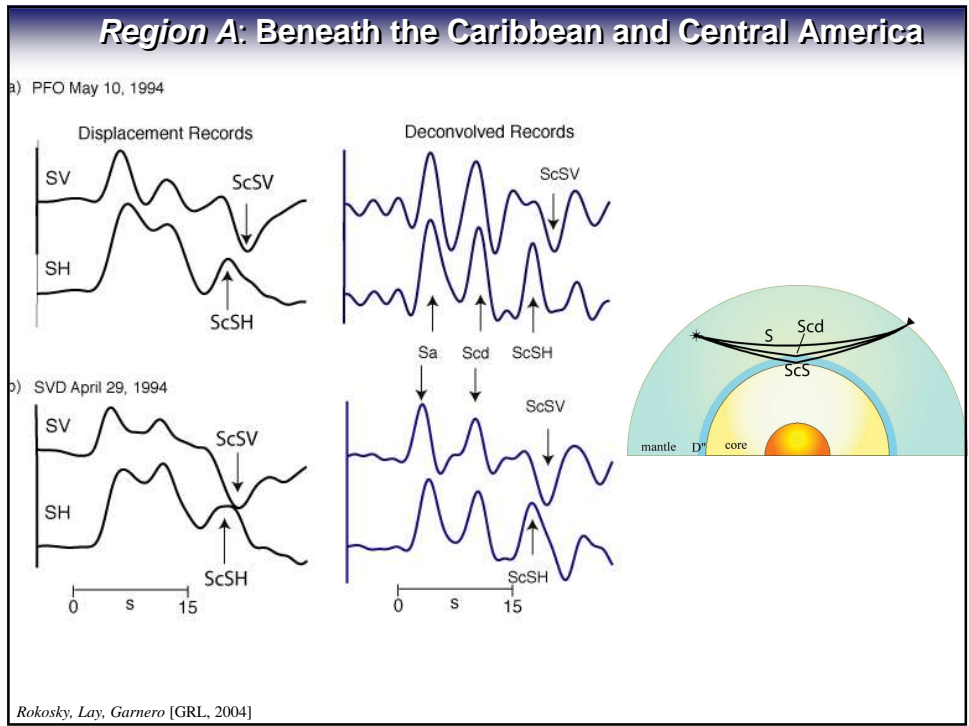


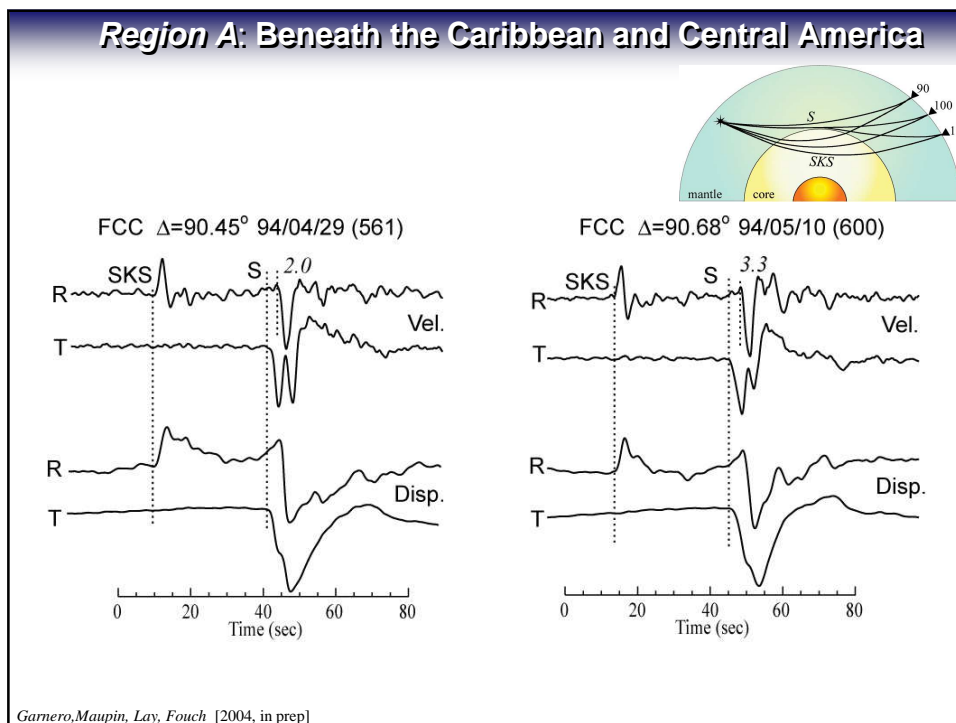
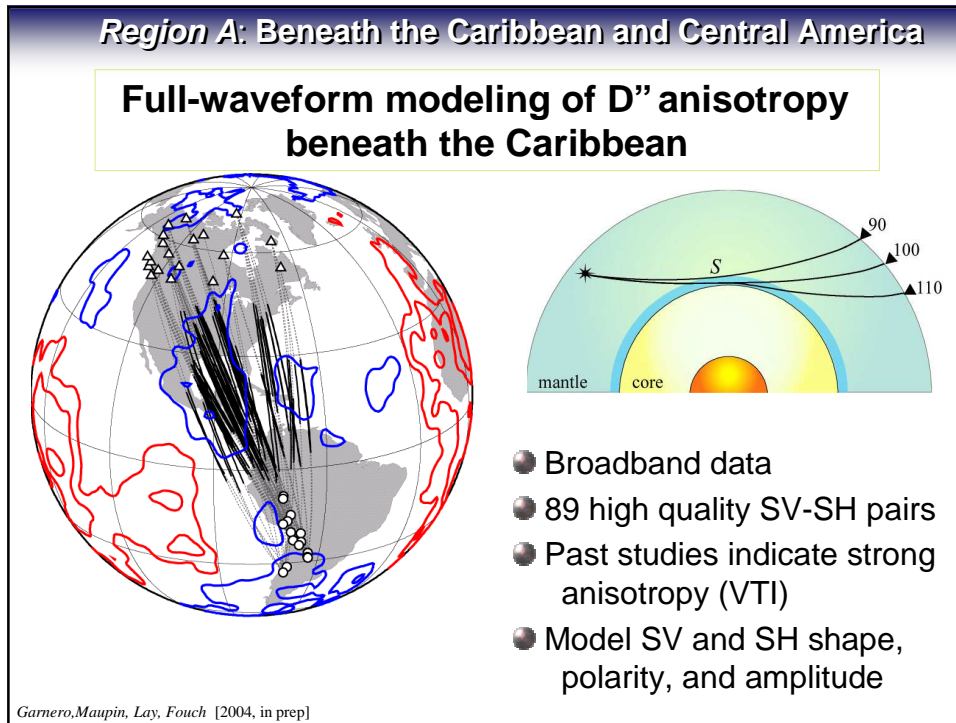
Lay, Garnero, Russell, GRL, 2004

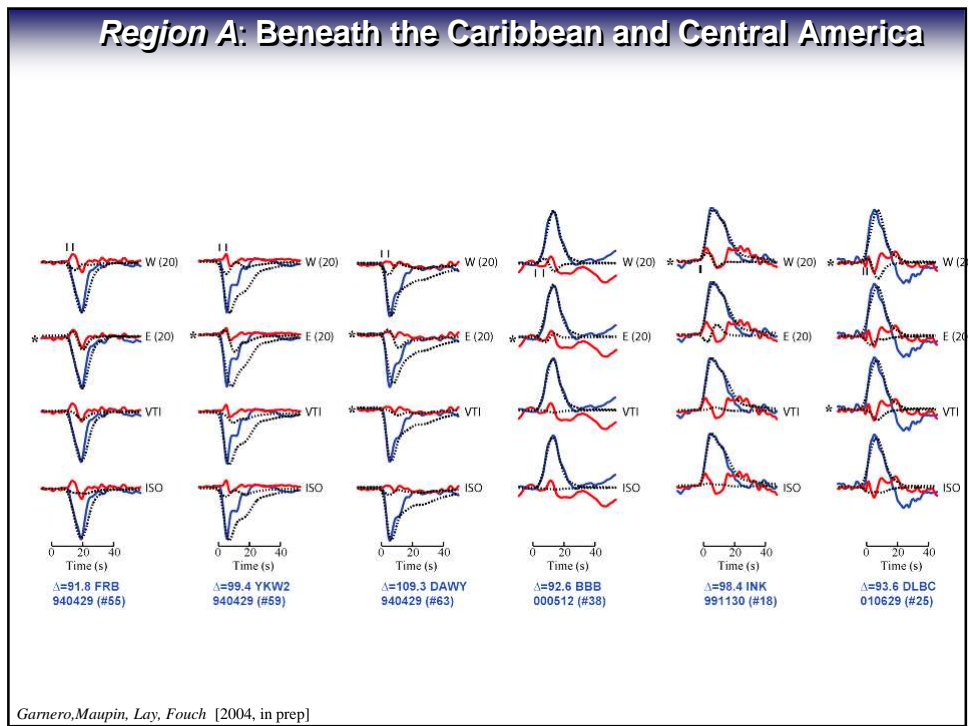
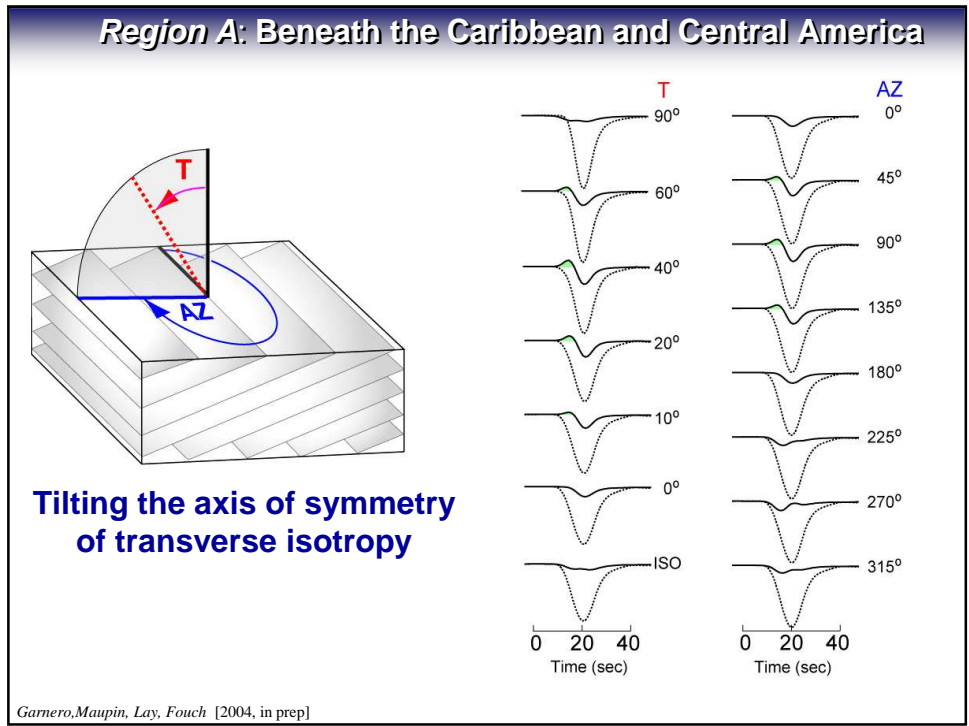


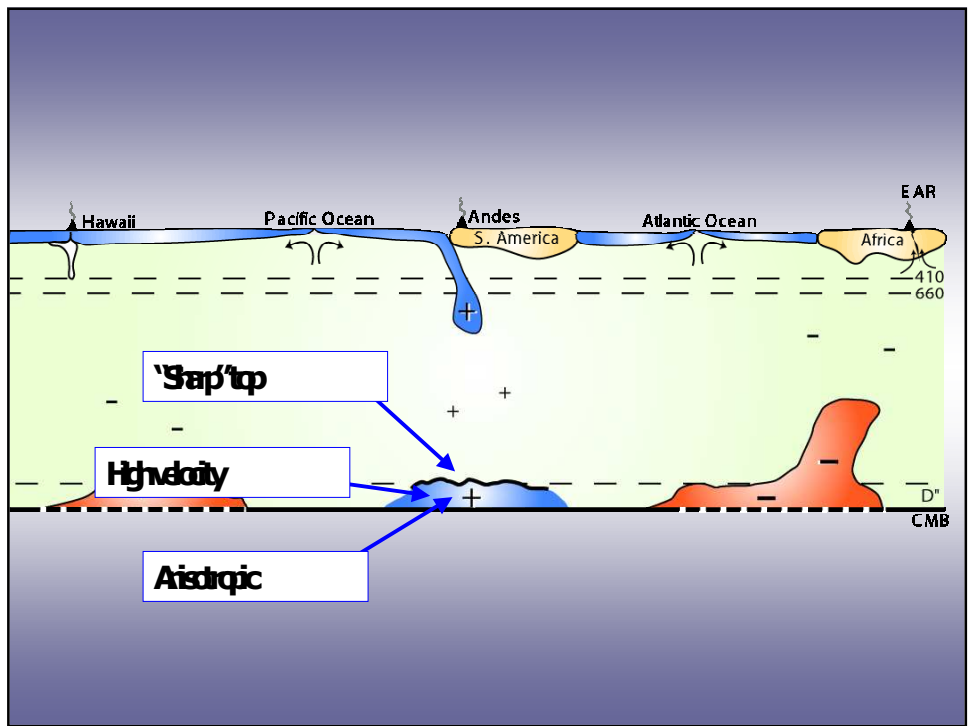
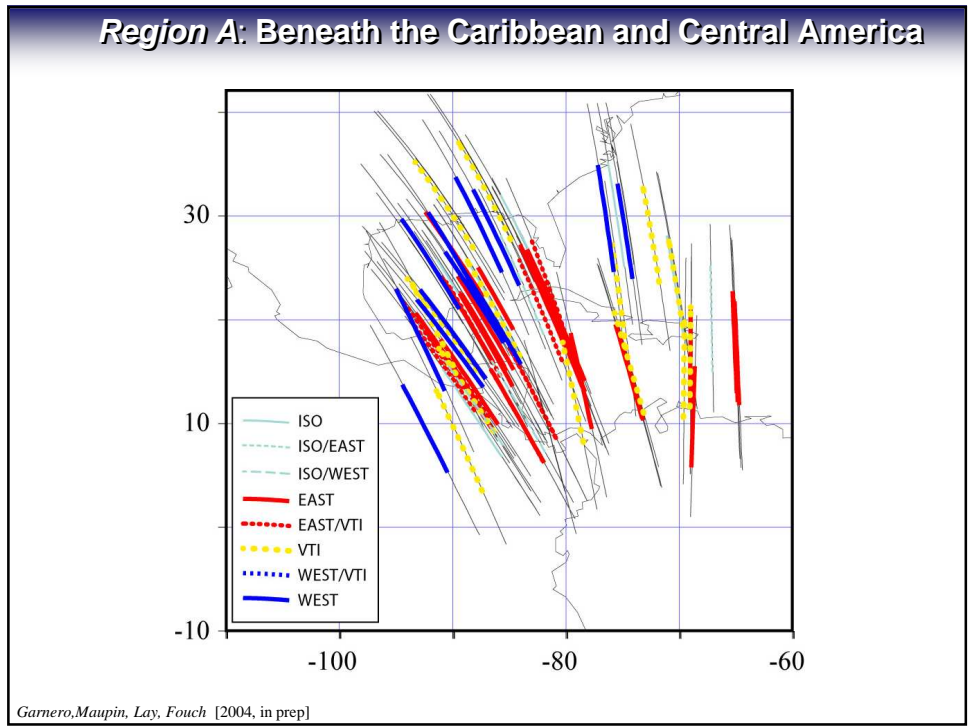








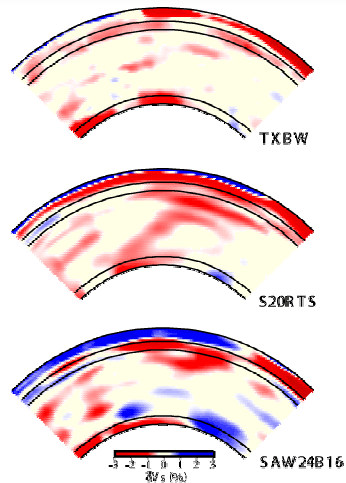
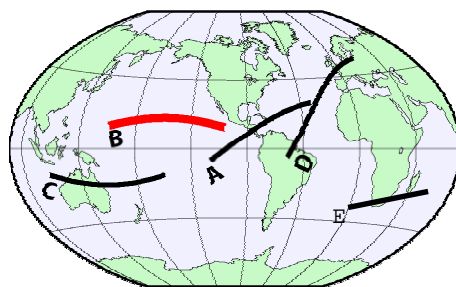




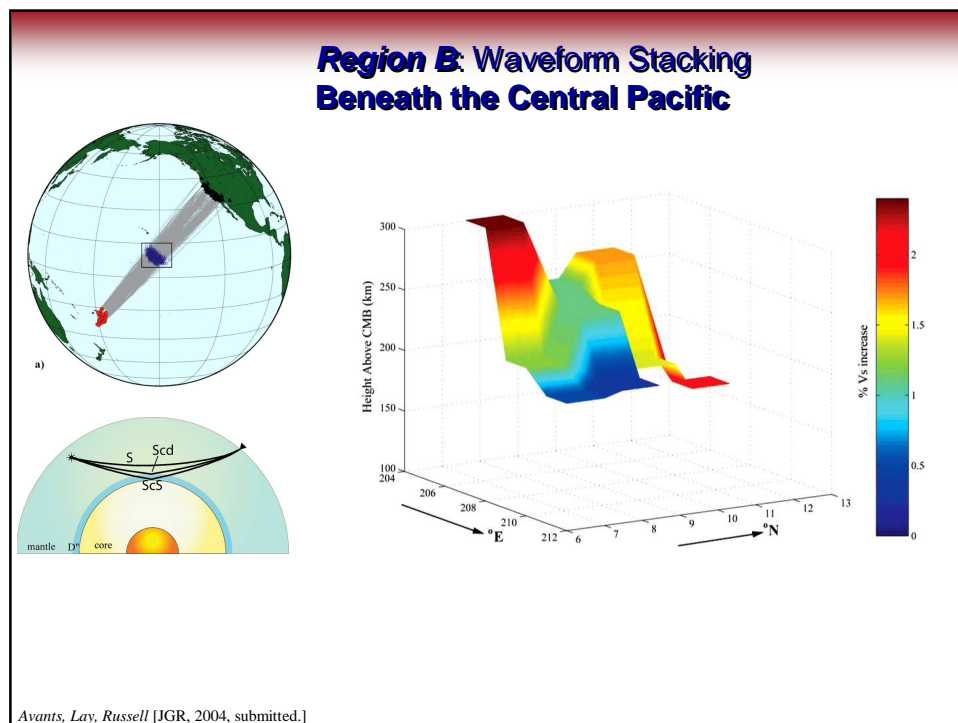
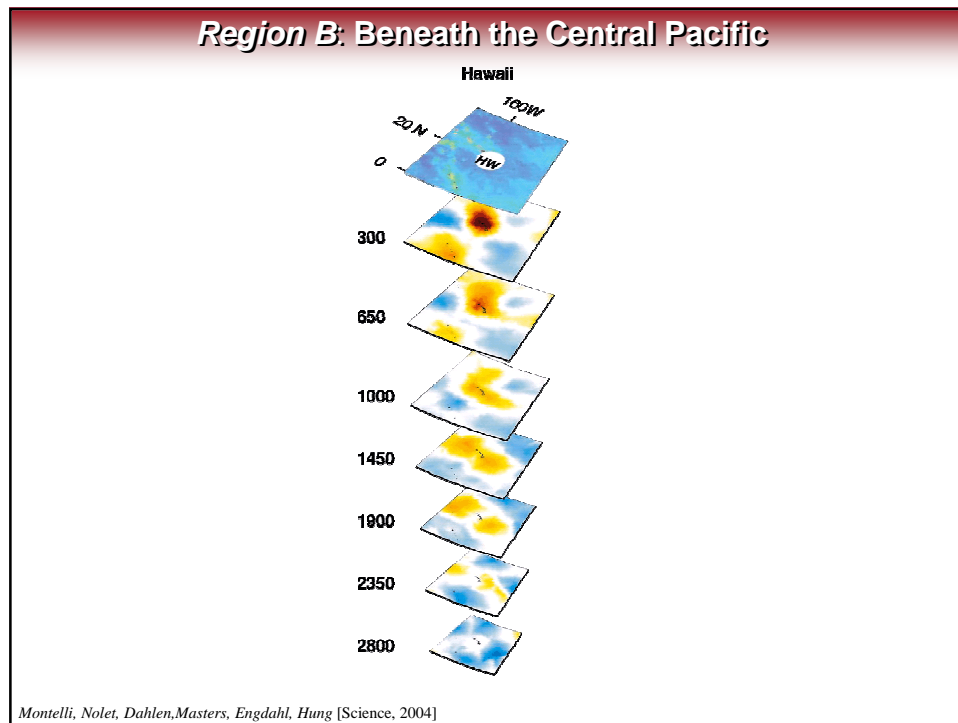
Regional Case Studies

- **A:** Beneath the Caribbean/Central America
- **B:** Beneath the central Pacific
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- **E:** Beneath South Africa, S. Atlantic, S. Indian Ocean

Region B: Beneath the Central Pacific



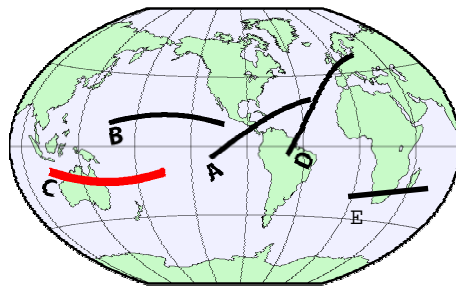
- **Strong heterogeneity**
- **D'' discontinuity**
- **D'' anisotropy**
- **Ultra-low velocity zone**



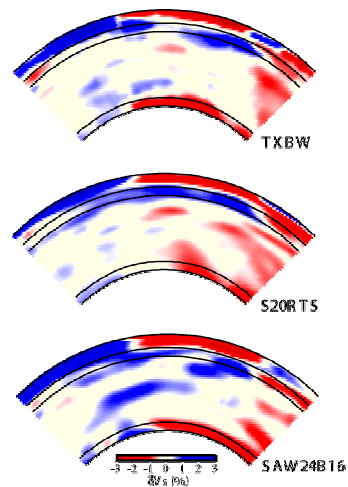
Regional Case Studies

- **A:** Beneath the Caribbean/Central America
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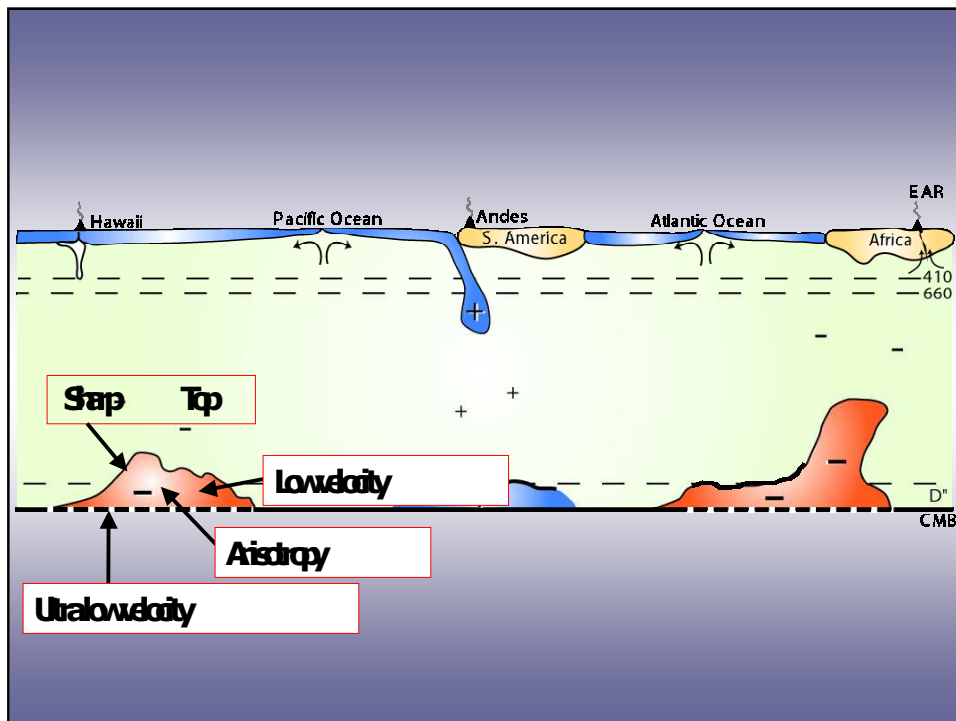
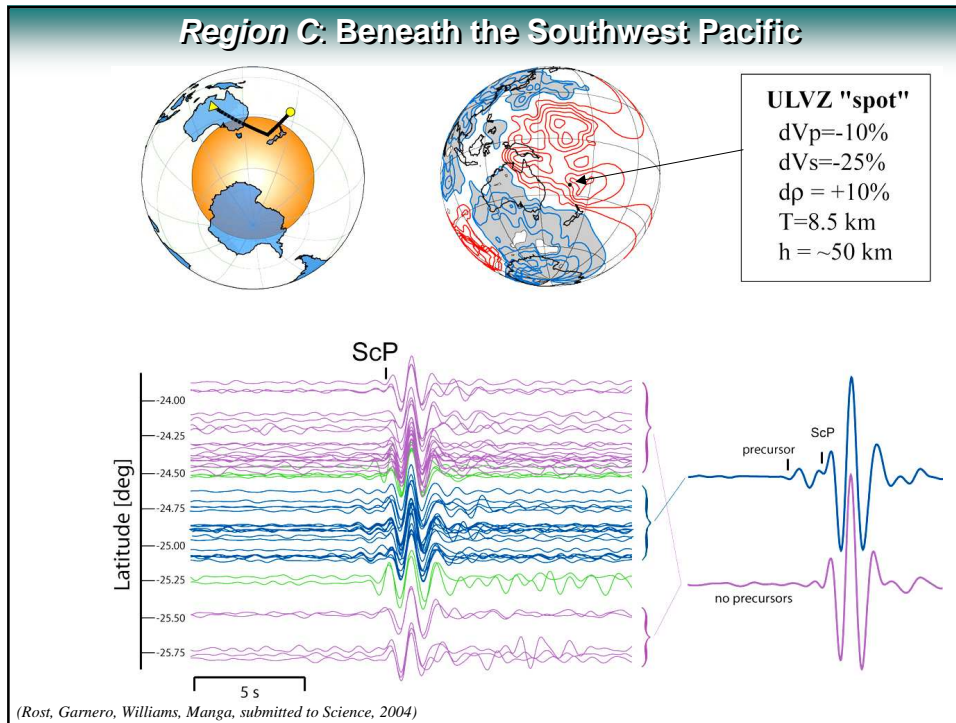
Region C: Beneath the Southwest Pacific



- **Strong heterogeneity**
- **Ultra-low velocity zone**

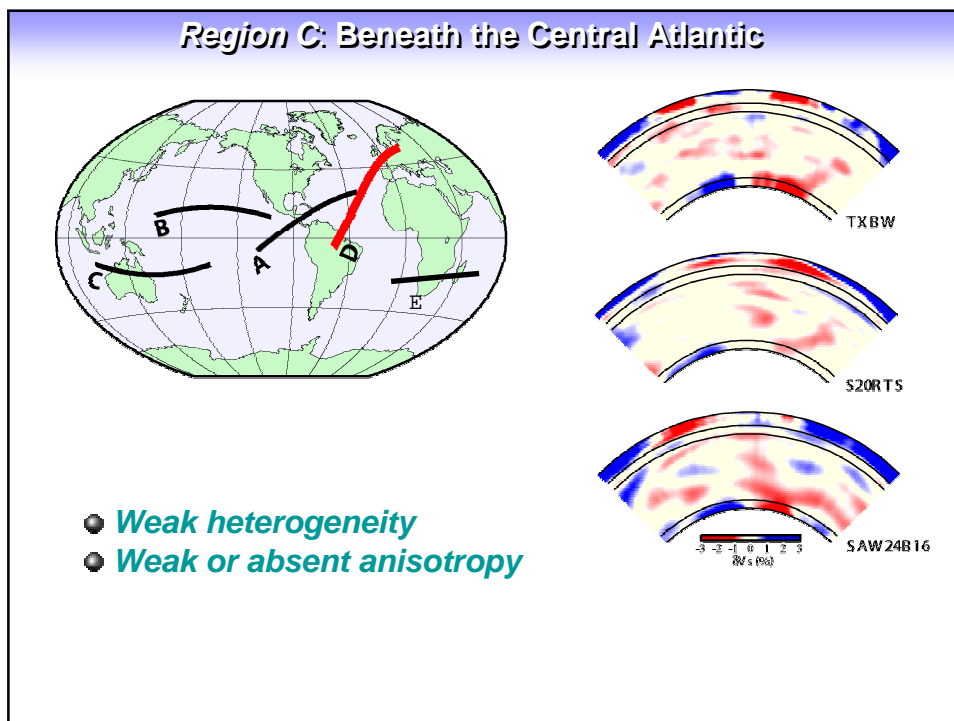


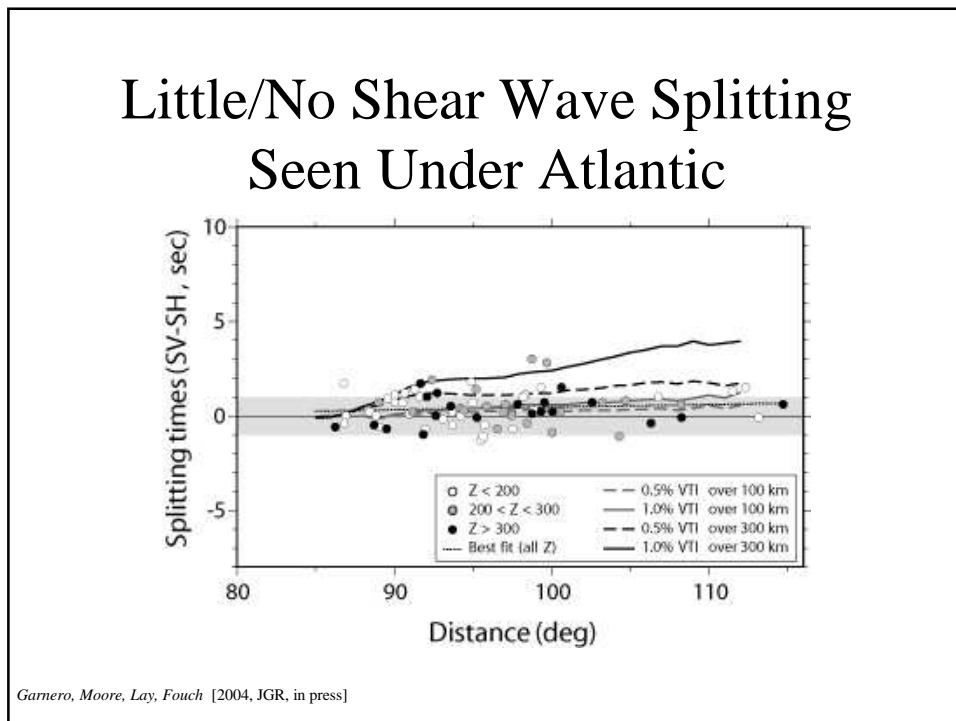
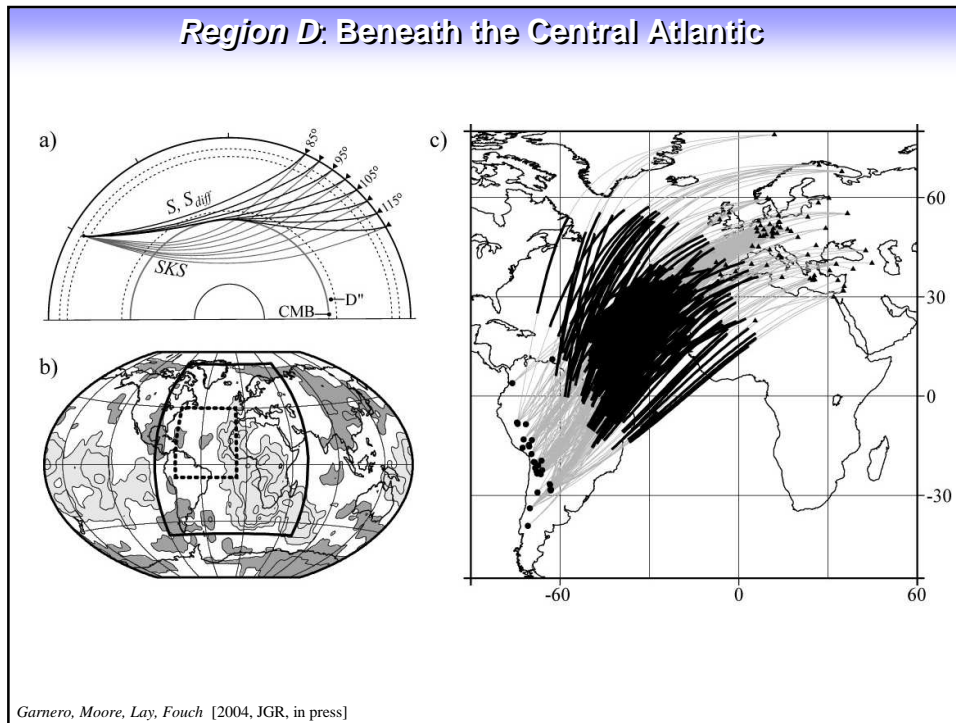
Lead Review: Seismology: Processes at the Core Mantle Boundary



Regional Case Studies

- **A:** Beneath the Caribbean/Central America
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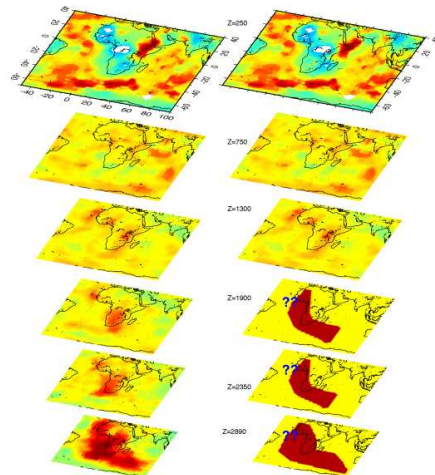




Regional Case Studies

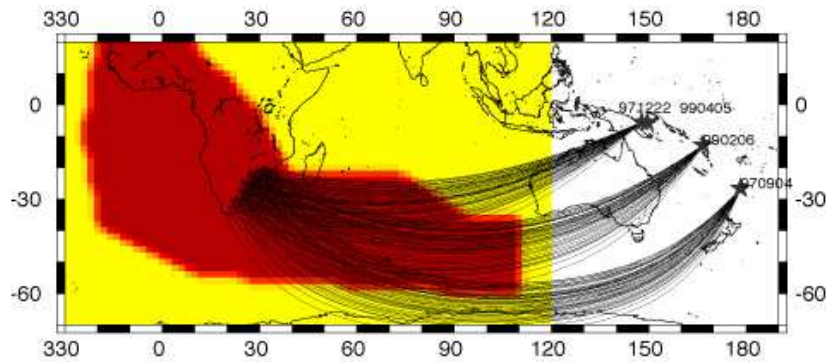
- **A:** Beneath the Caribbean/Central America
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Region E: Southern Africa/Atlantic/Indian Ocean LVP



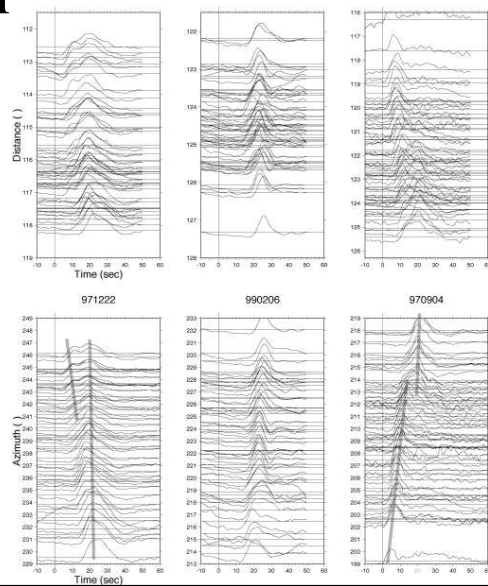
Ni and Helmberger, 2004

LVP has Strong Lateral Edges

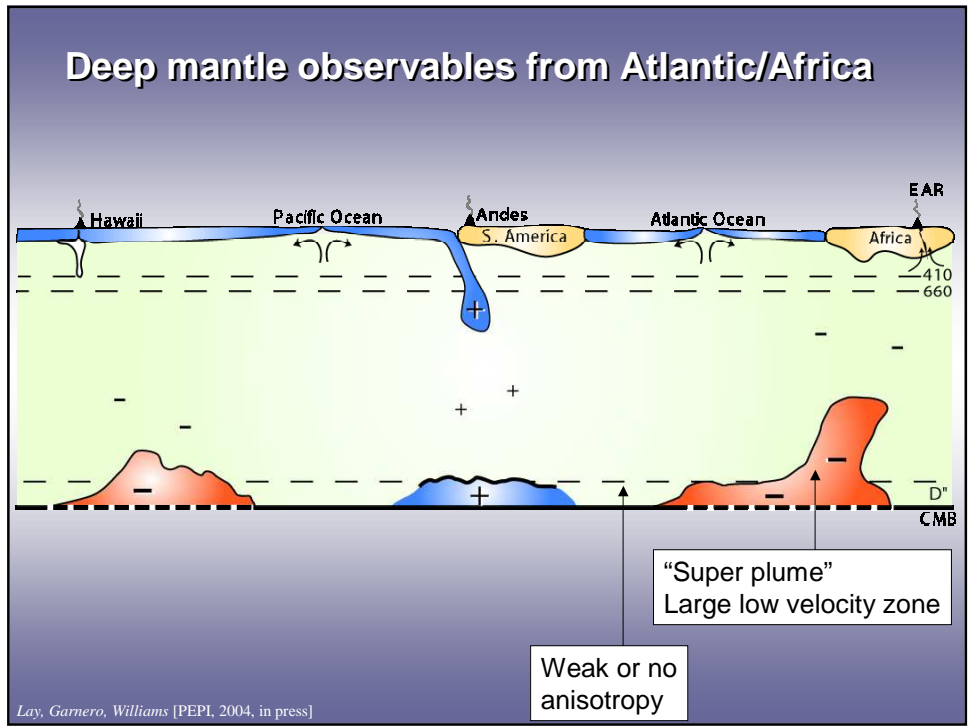


Ni and Helmberger, 2004

Azimuthal and Distance Dominate



Ni and Helmberger, 2004

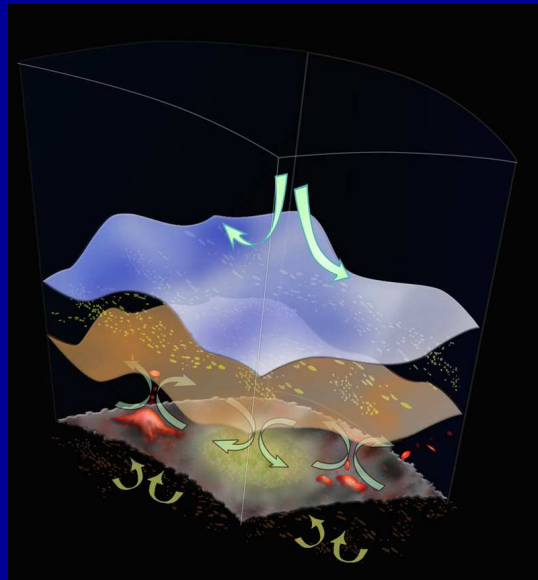


Summing up....

D'' and the CMB are as structurally and dynamically complex as the Earth's surface boundary layer.

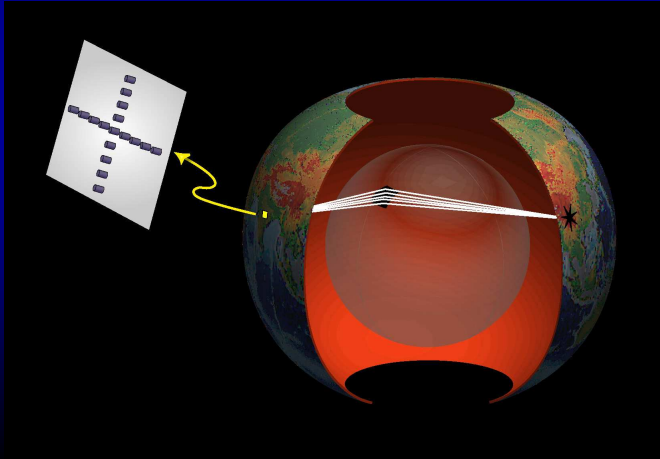
Some specifics:

- Deep mantle heterogeneity is strong at short scales of 50-100 km
- D'' discontinuity has highly variable topography on large and small scales
- Strong evidence for D'' azimuthal anisotropy over large regions (close to VTI) in some cases, far from it in others
- Ultra-low velocity zones may be extremely localized, and could involve local boundary layer instabilities



Next Steps...

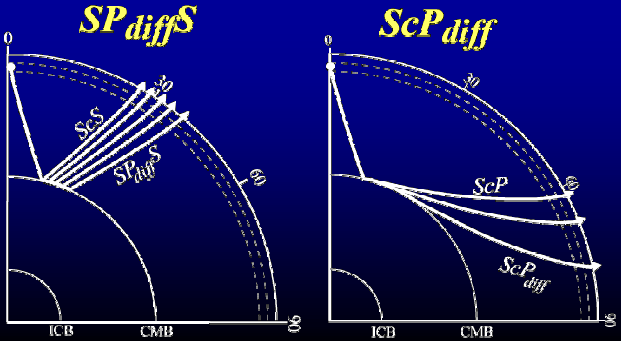
- Better seismic wavefield characterization
 - more array analysis methods
 - shorter wavelengths
 - frequency dependence



The diagram shows a cross-section of the Earth with the core and mantle. A seismic wave is shown propagating from the core-mantle boundary towards a seismic array on the surface. The array is represented by a grid of sensors. A yellow arrow points from the wave towards the array.

Next Steps...

- Better seismic wavefield characterization
 - more array analysis methods
 - shorter wavelengths
 - frequency dependence
- New probes of the interior
 - many unexploited possibilities exist




The two diagrams show seismic wave propagation paths. The left diagram is labeled *SPdiffS* and shows waves originating from the inner core boundary (ICB) and reflecting off the core-mantle boundary (CMB). The right diagram is labeled *ScPdiff* and shows waves originating from the inner core boundary (ICD) and reflecting off the core-mantle boundary (CMB). Both diagrams show the paths of the waves and their reflection off the boundaries.

Rost and Garnero [in prep]

Next Steps...

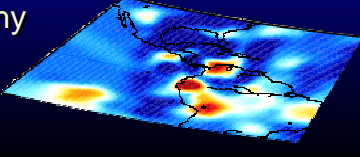
- Better seismic wavefield characterization
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 - shorter wavelengths
 - frequency dependence
- New probes of the interior
 - many unexploited possibilities exist
- Better wave propagation tools
 - 2 and 3D tools mandatory



Thorne, Garnero, Igel, Treml, Jahnke, Schmerr [in prep]

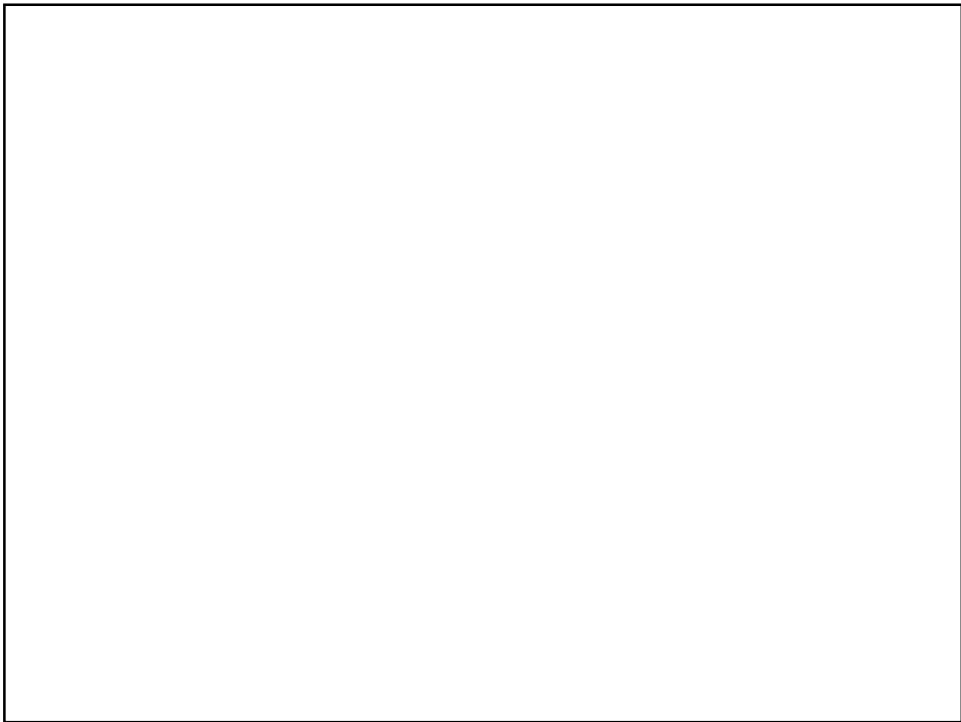
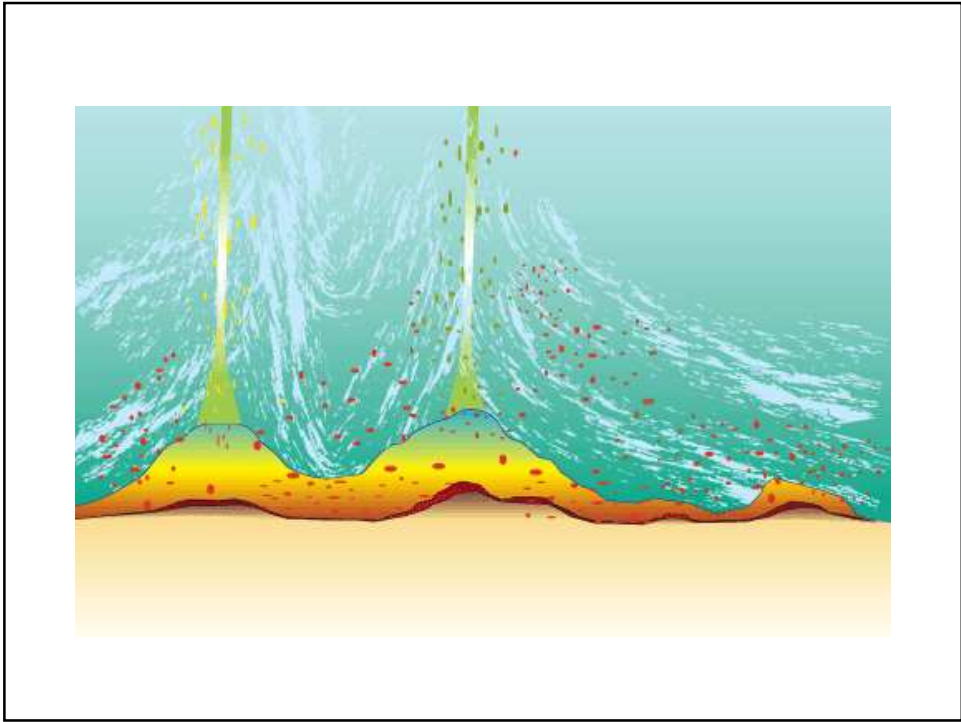
Next Steps...

- Better seismic wavefield characterization
 - more array analysis methods
 - shorter wavelengths
 - frequency dependence
- New probes of the interior
 - many unexploited possibilities exist
- Better wave propagation tools
 - 2 and 3D tools mandatory
- Better inversions:
 - finite frequency tomography



Hung, Garnero, Chiao, Kuo, Lay [2004, in prep]

Lead Review: Seismology: Processes at the Core Mantle Boundary



Evidence for a Thermal Boundary Layer in D''

- P and S velocity gradient **decreases** in the lowermost 200 km of the mantle - this was basis of defining D'' in the first place (weak constraint)
- Geodynamo energetics require 2-10 TW/yr heat flowing from core into mantle (strong constraint)
- Extrapolations of temperature estimates along adiabats upward from inner core boundary and downward from 410-km/660-km phase transitions in $(\text{Mg,Fe})_2\text{SiO}_4$ predict 1000-1500K superadiabatic temperature increase across D'' (moderate constraint)

Evidence for chemical heterogeneity in D''

- Rapid P and S velocity **increases** at top of D'' in **high** velocity regions (moderate constraint)
- Rapid P and S velocity **decreases** at top of D'' in **low** velocity regions (moderate constraint)
- Short and large scale topography of these increases/decreases (strong constraint)
- Intense lateral velocity gradients into low velocity regions (strong constraint)
- S wave velocity heterogeneity disproportionate to P (strong constraint)
- Ultralow velocity zones at CMB - likely melt/chemical differentiation expected (moderate constraint)
- Seismic wave scattering at short scales (strong constraint)

Lead Review: Seismology: Processes at the Core Mantle Boundary

