The Earth’s Structure from Travel Times

Spherically symmetric structure: PREM

- Crustal Structure

- Upper Mantle structure
    - Phase transitions
    - Anisotropy

- Lower Mantle Structure
    - D”

- Structure of the Outer and Inner Core

3-D Structure of the Mantle from Seismic Tomography

- Upper mantle

- Mid mantle

- Lower Mantle

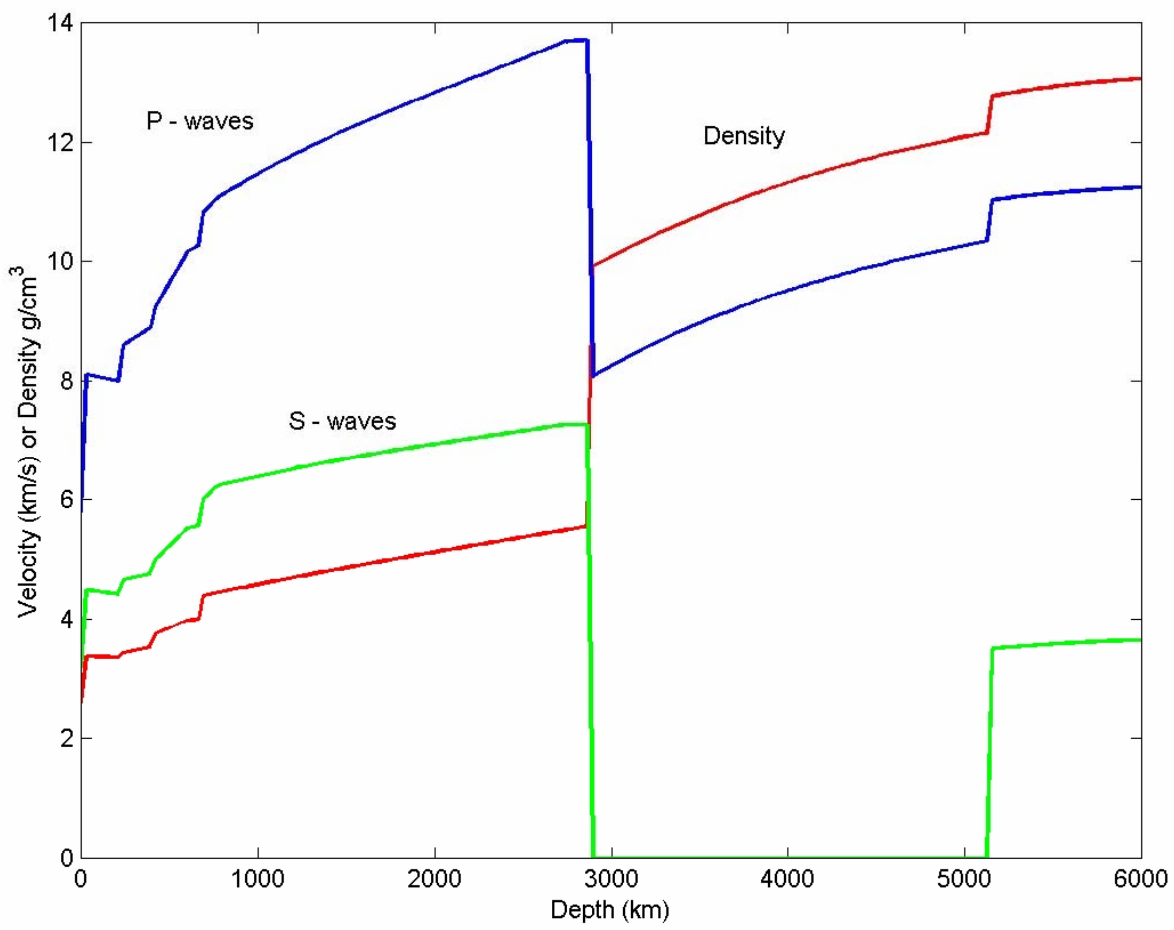
Spherically Symmetric Structure

Parameters which can be determined for a reference model

- P-wave velocity
- S-wave velocity
- Density
- Attenuation (Q)
- Anisotropic parameters
- Bulk modulus K_s
- rigidity μ
- pressure
- gravity

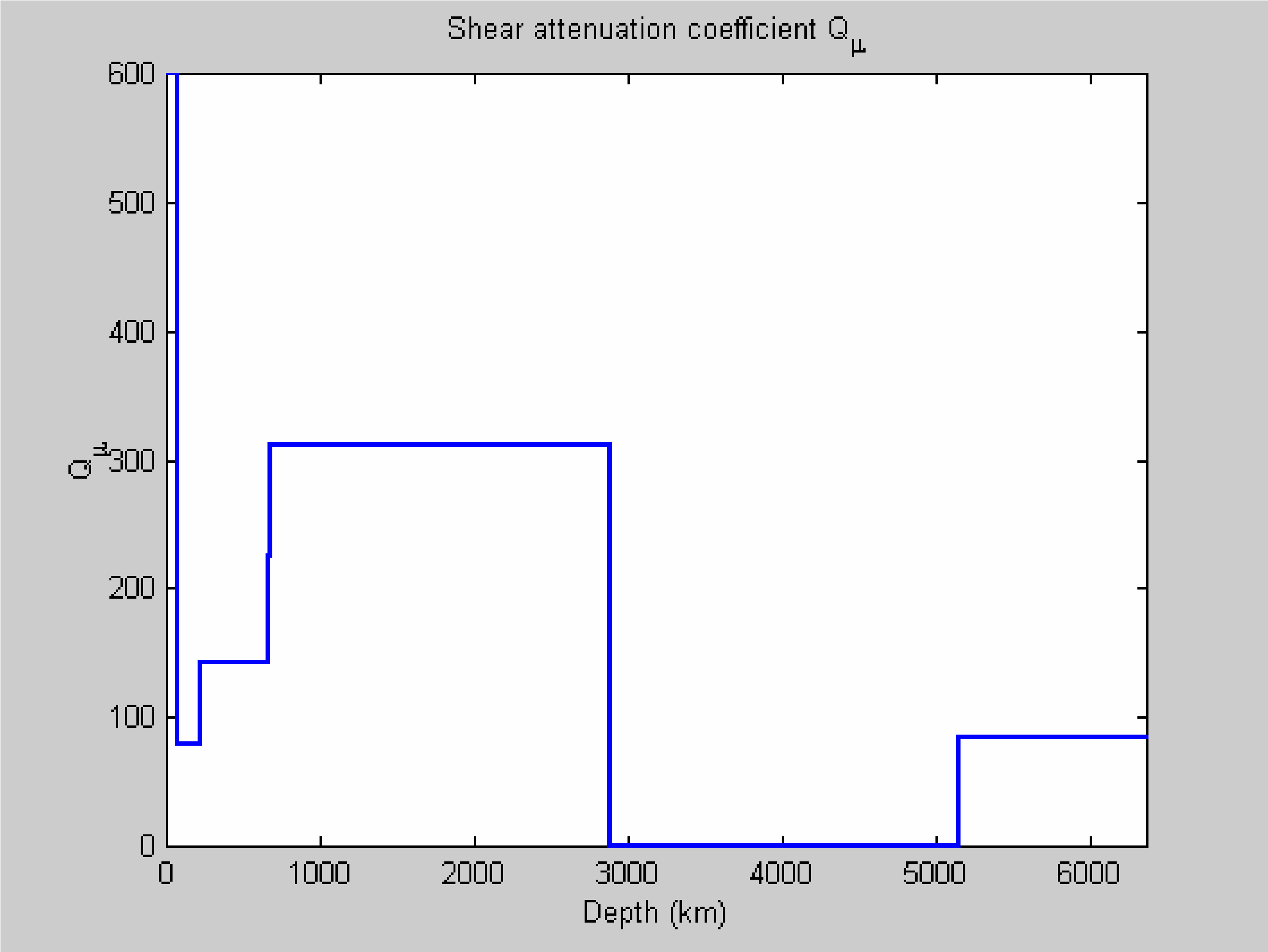
PREM: velocities and density

PREM: Preliminary Reference Earth Model (Dziewonski and Anderson, 1981)



PREM: Attenuation

PREM: Preliminary Reference Earth Model (Dziewonski and Anderson, 1981)



Earth’s Regions and Fractional Mass

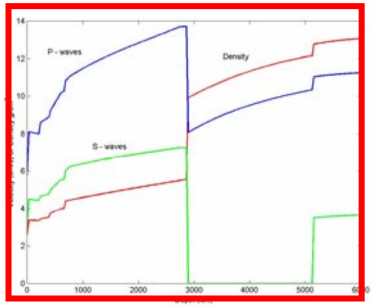
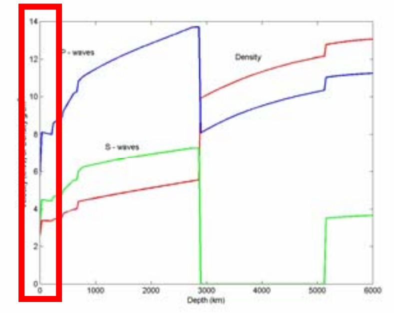
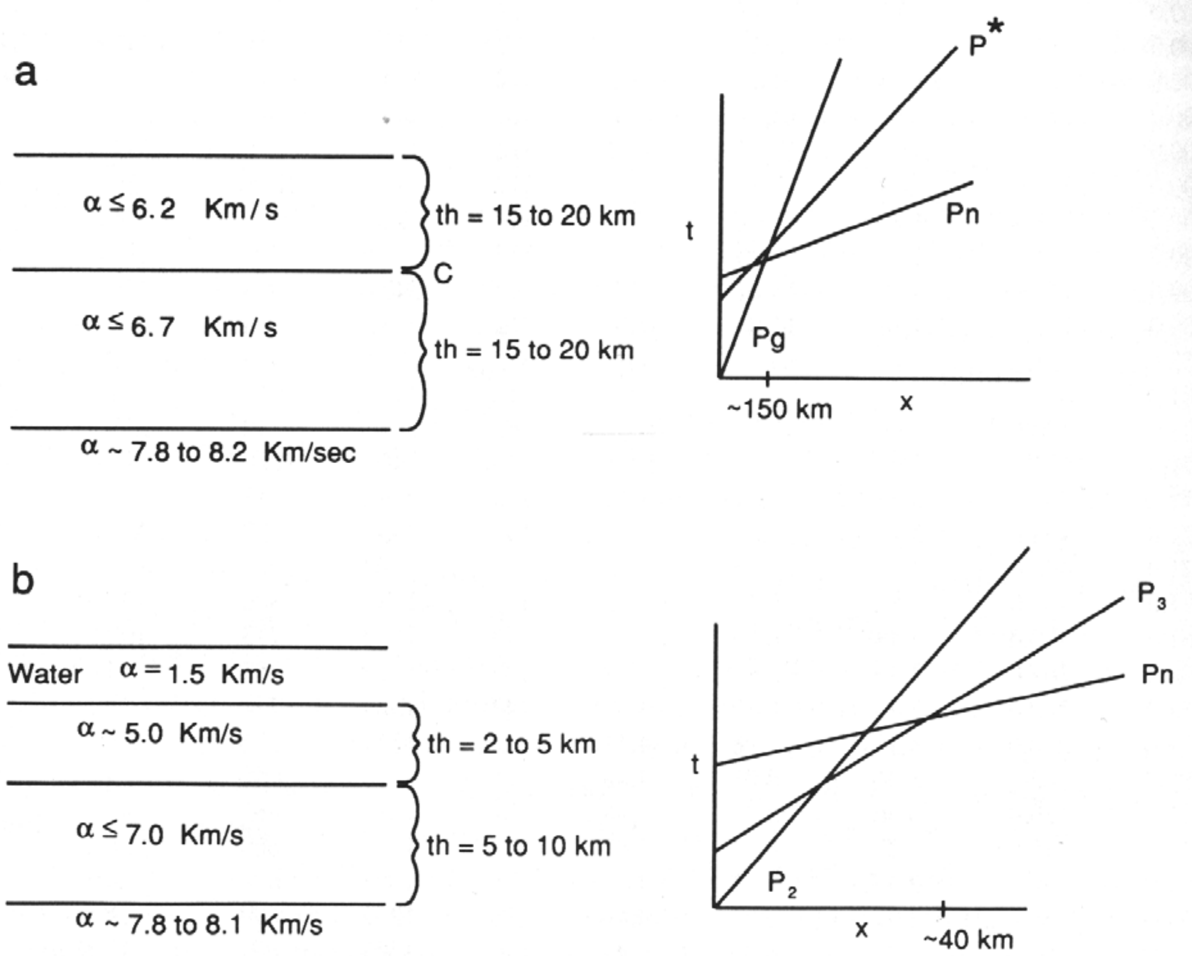


TABLE 3-1
Summary of Earth Structure

Region	Depth (km)	Fraction of Total Earth Mass	Fraction of Mantle and Crust
Continental crust	0–50	0.00374	0.00554
Oceanic crust	0–10	0.00099	0.00147
Upper mantle	10–400	0.103	0.153
Transition region	400–650	0.075	0.111
Lower mantle	650–2890	0.492	0.729
Outer core	2890–5150	0.308	—
Inner core	5150–6370	0.017	—

The Earth's Crust: Travel Times





Continental crust (a) and oceanic crust (b) with corresponding travel-time curves

The Earth's Crust: Minerals and Velocities

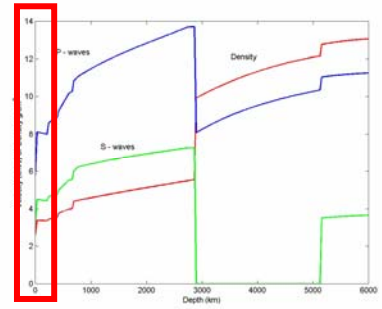
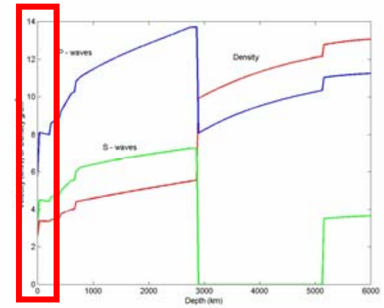


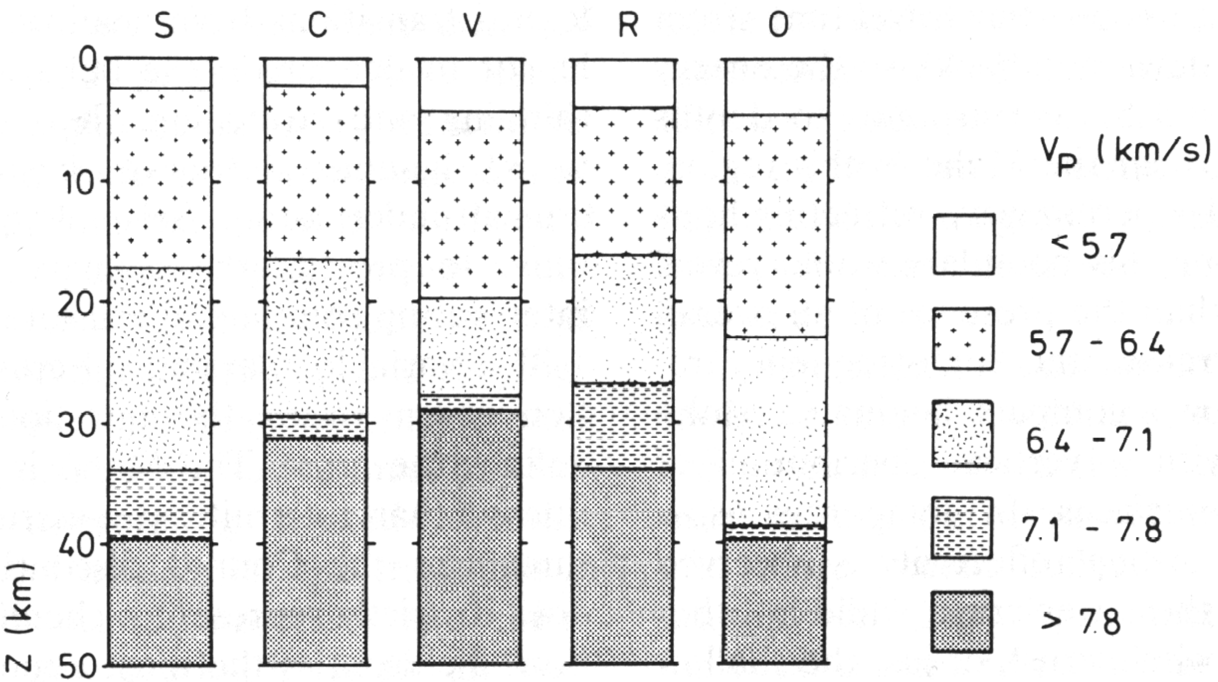
TABLE 3-3
Average Crustal Abundance, Density and Seismic Velocities of Major Crustal Minerals

Mineral	Volume percent	ρ (g/cm^3)	V_p (km/s)	V_s (km/s)
Quartz	12	2.65	6.05	4.09
K-feldspar	12	2.57	5.88	3.05
Plagioclase	39	2.64	6.30	3.44
Micas	5	2.8	5.6	2.9
Amphiboles	5	3.2	7.0	3.8
Pyroxene	11	3.3	7.8	4.6
Olivine	3	3.3	8.4	4.9

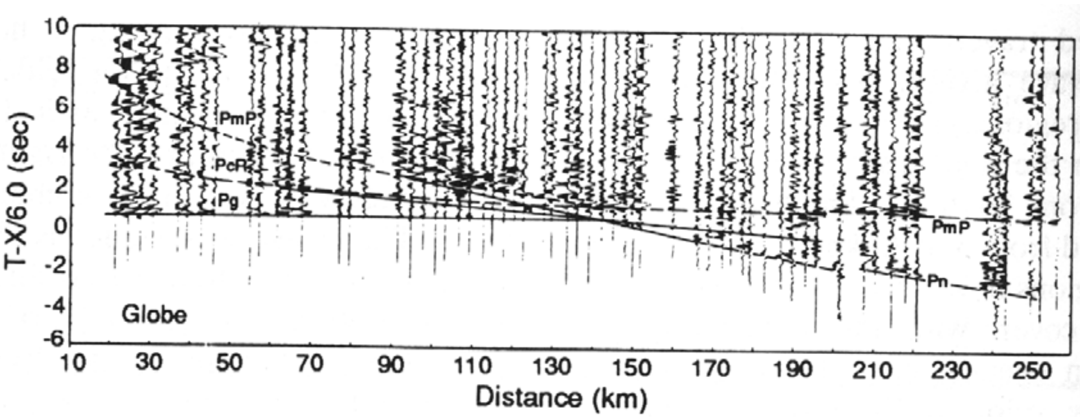
Average crustal abundance, density and seismic velocities of major crustal minerals.

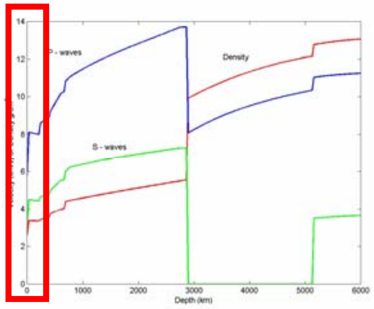
The Earth's Crust: Crustal Types

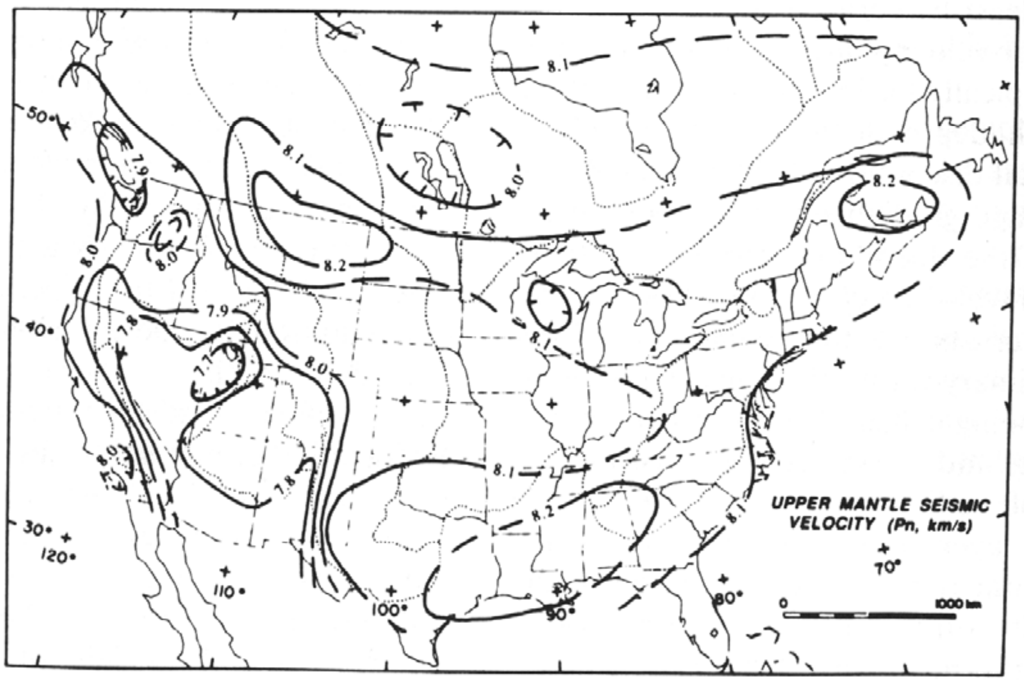




S shields, C Caledonian provinces, V Variscan provinces, R rifts, O orogens



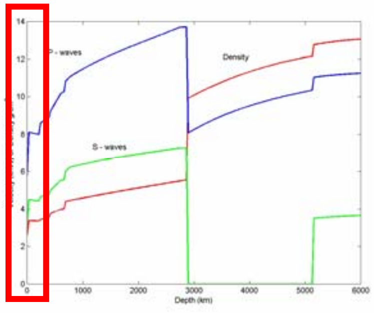


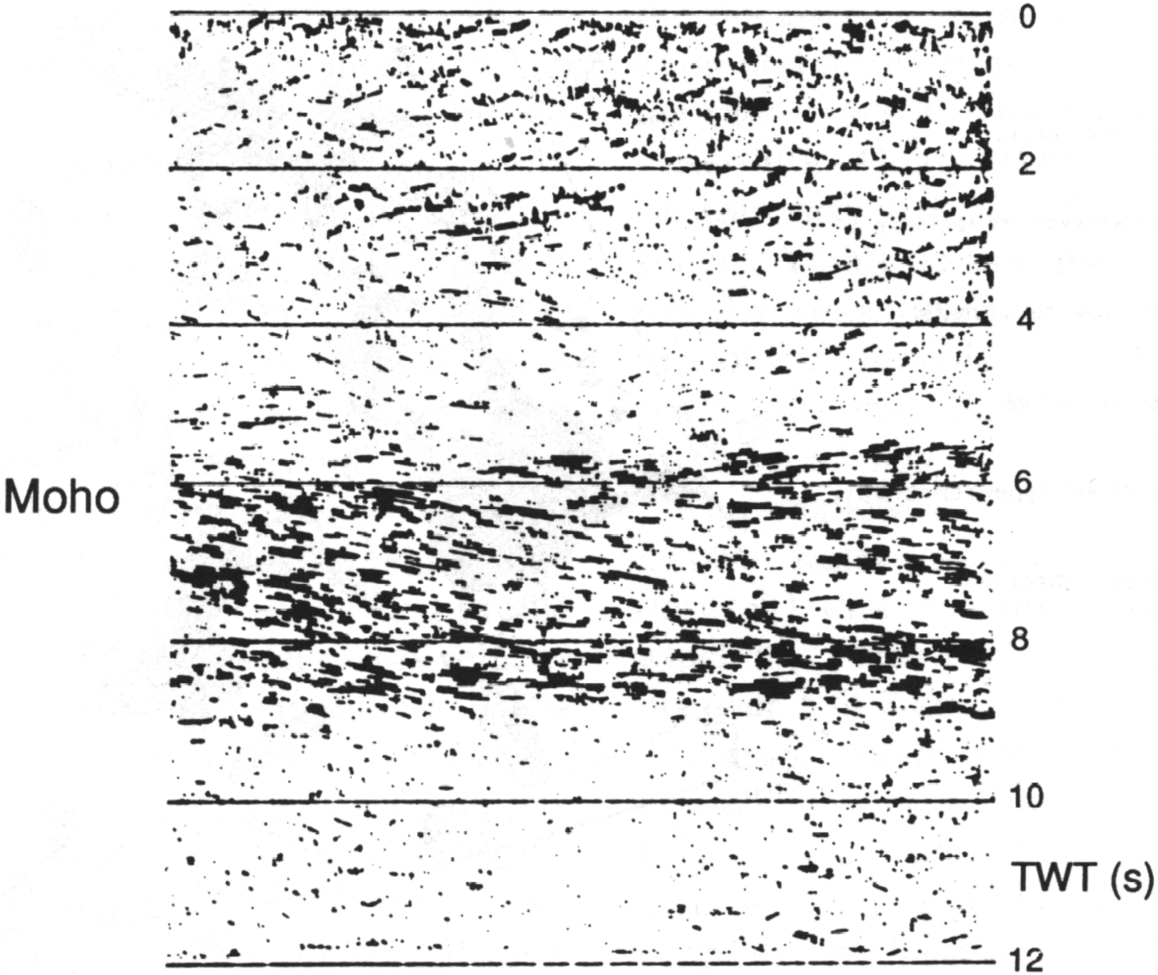


Refraction profiles across North America, (reduction velocity 6km/s) all the determination of lateral velocity variations:

PmP Moho reflection
Pn Moho refraction
Pg direct crustal wave

The Earth's crust: Crustal Types

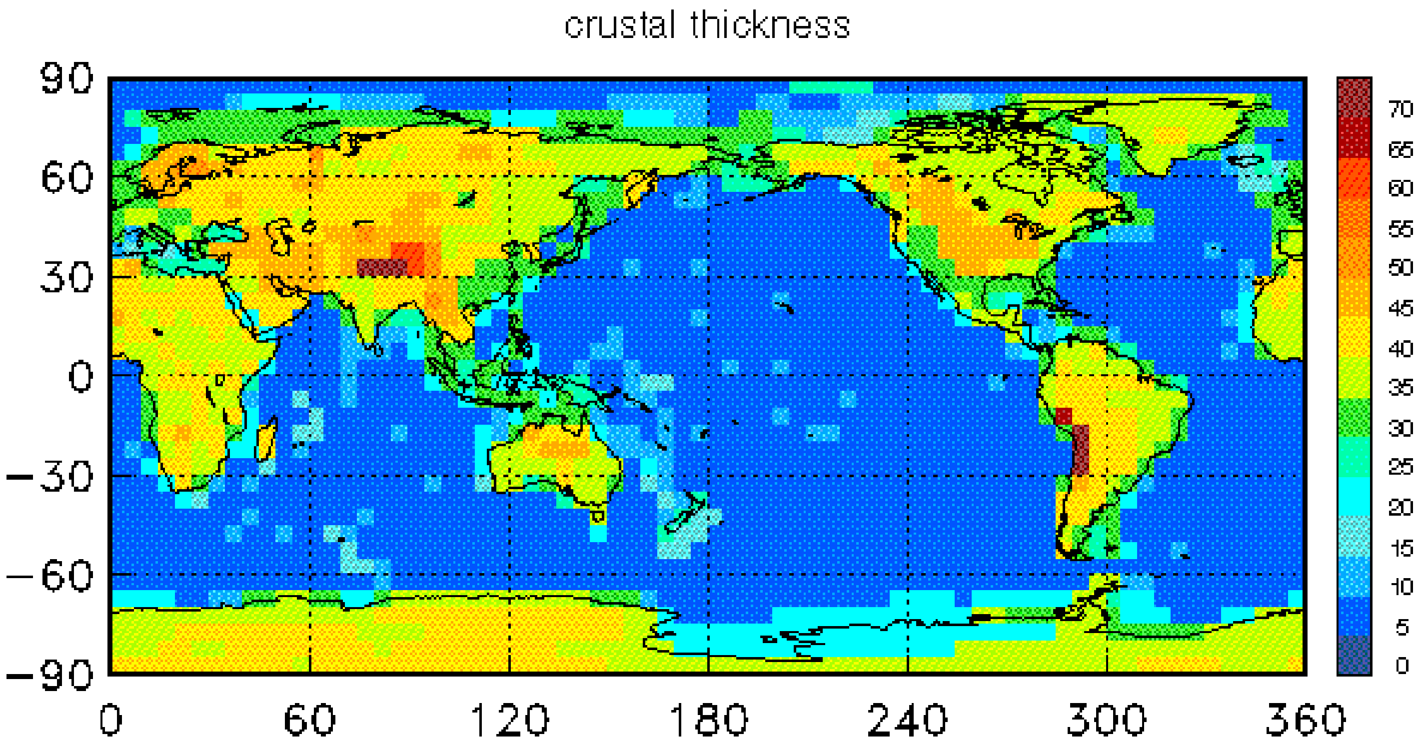


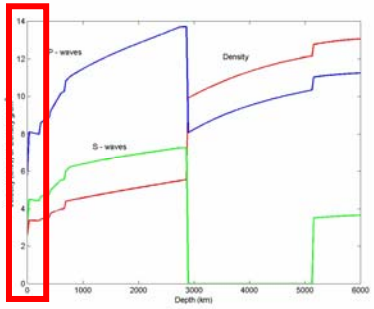


Reflection data often show a highly reflective lower crust. This may indicate fine layering or lamination, some transition from crust to upper mantle.

TWT two-way traveltimes

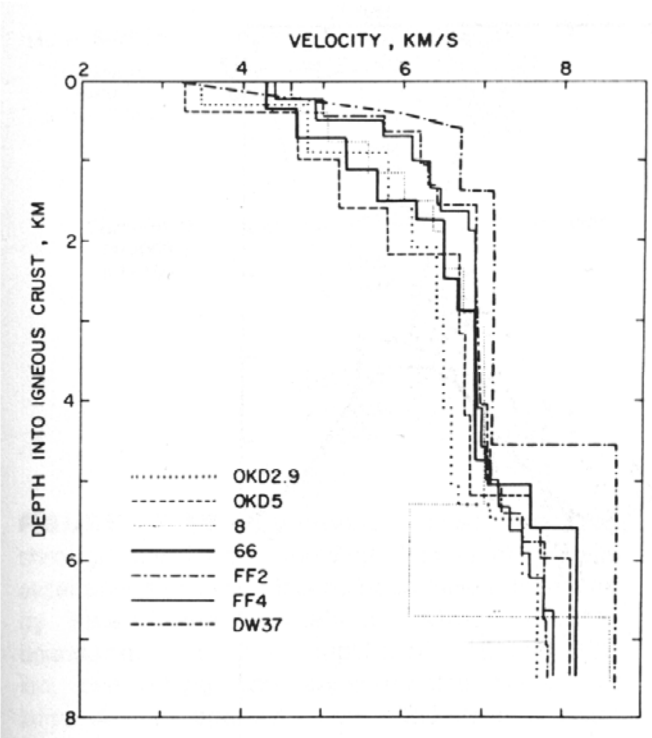
The Earth's crust: Crustal Types

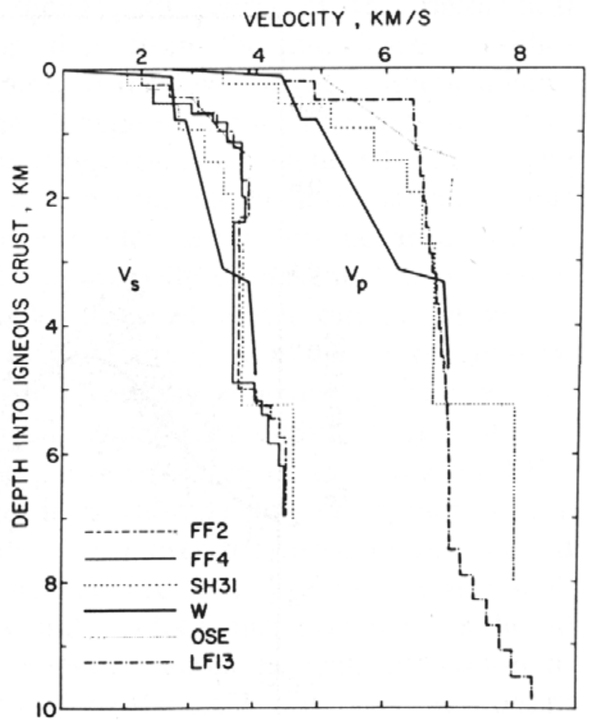


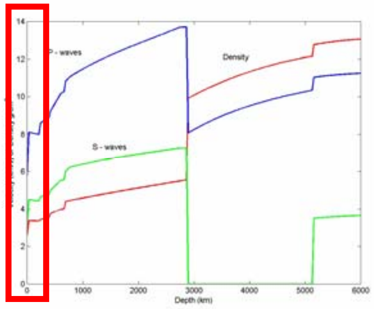


Recently compiled world-wide crustal thickness (km) indicates cratonic areas and mountain ranges with active tectonics. These data are important to correct travel times regionally, i.e. calculate the contribution of crustal thickness to a teleseismic travel-time perturbation.

The Earth's crust: Crustal Types

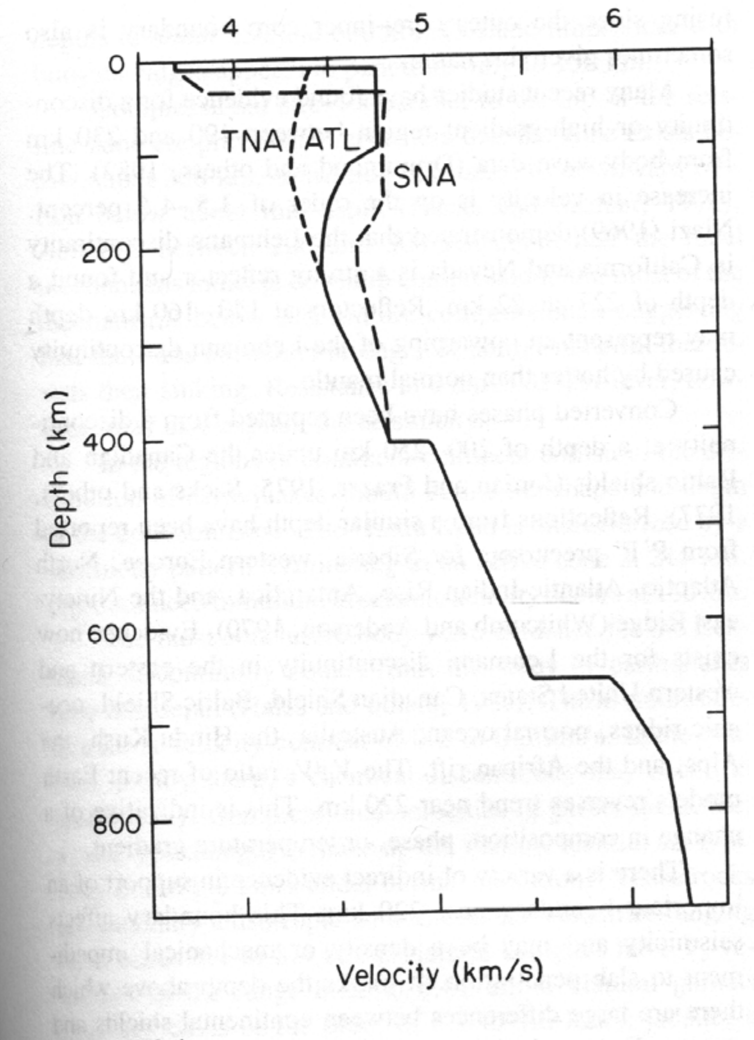




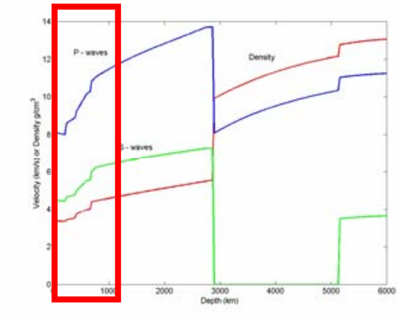


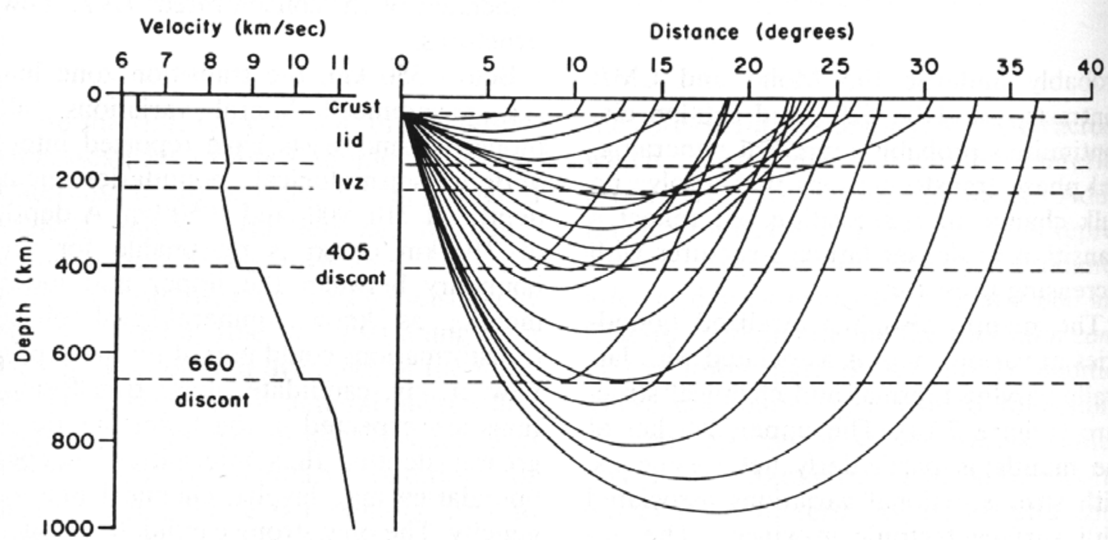
Left: Crust P-velocity profiles for young (<20 million year) oceanic basin structures. Right: Crustal P and S velocities for oceanic regions older than 20 million years.

The Earth's Upper Mantle: Athenosphere



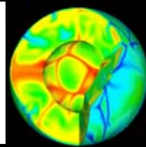
The high-velocity lid above the low velocity zone (asthenosphere) is called the lithosphere.

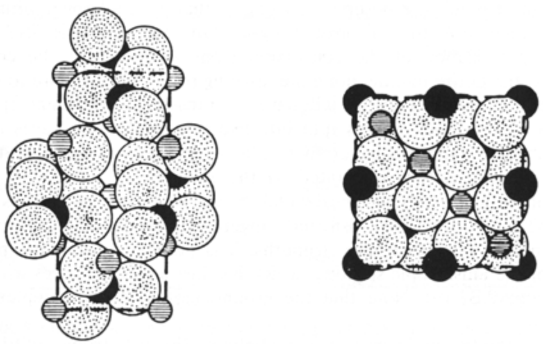




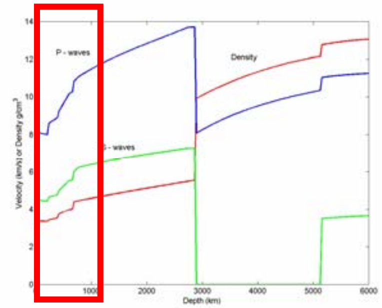
The upper-mantle velocity structure leads to complex ray paths.

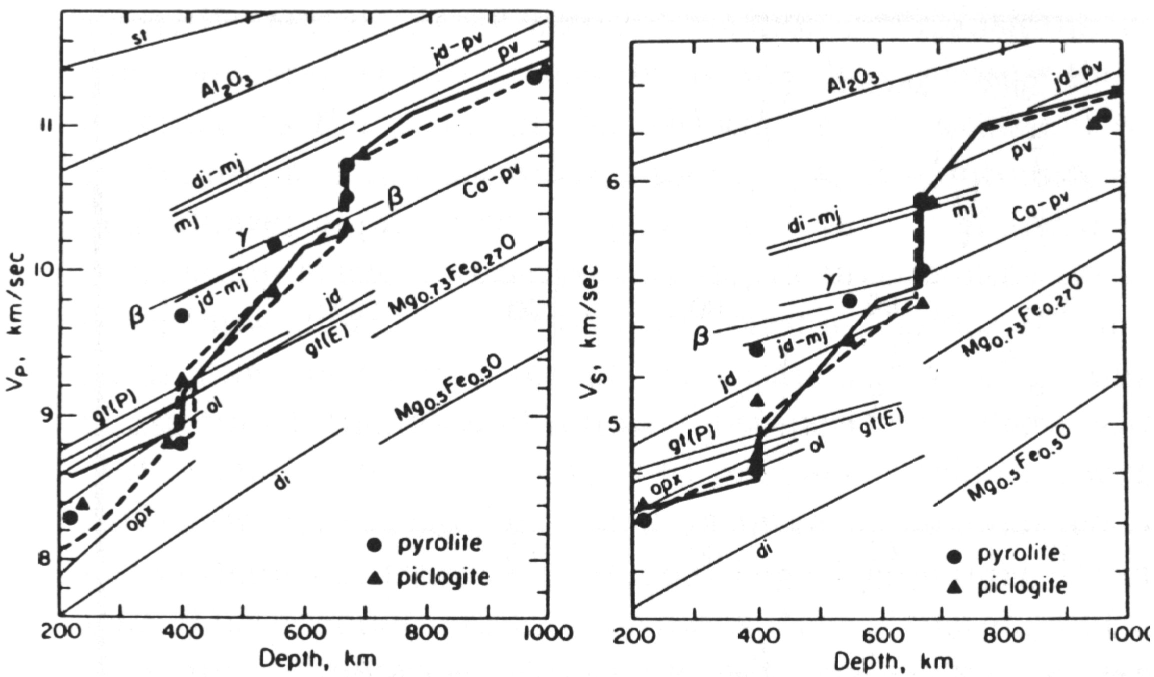
Upper Mantle: Phase transitions





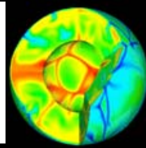
Upper mantle discontinuities (e.g. 410km) are caused by phase transitions (left: low pressure olivine, right: high pressure β-spinel)

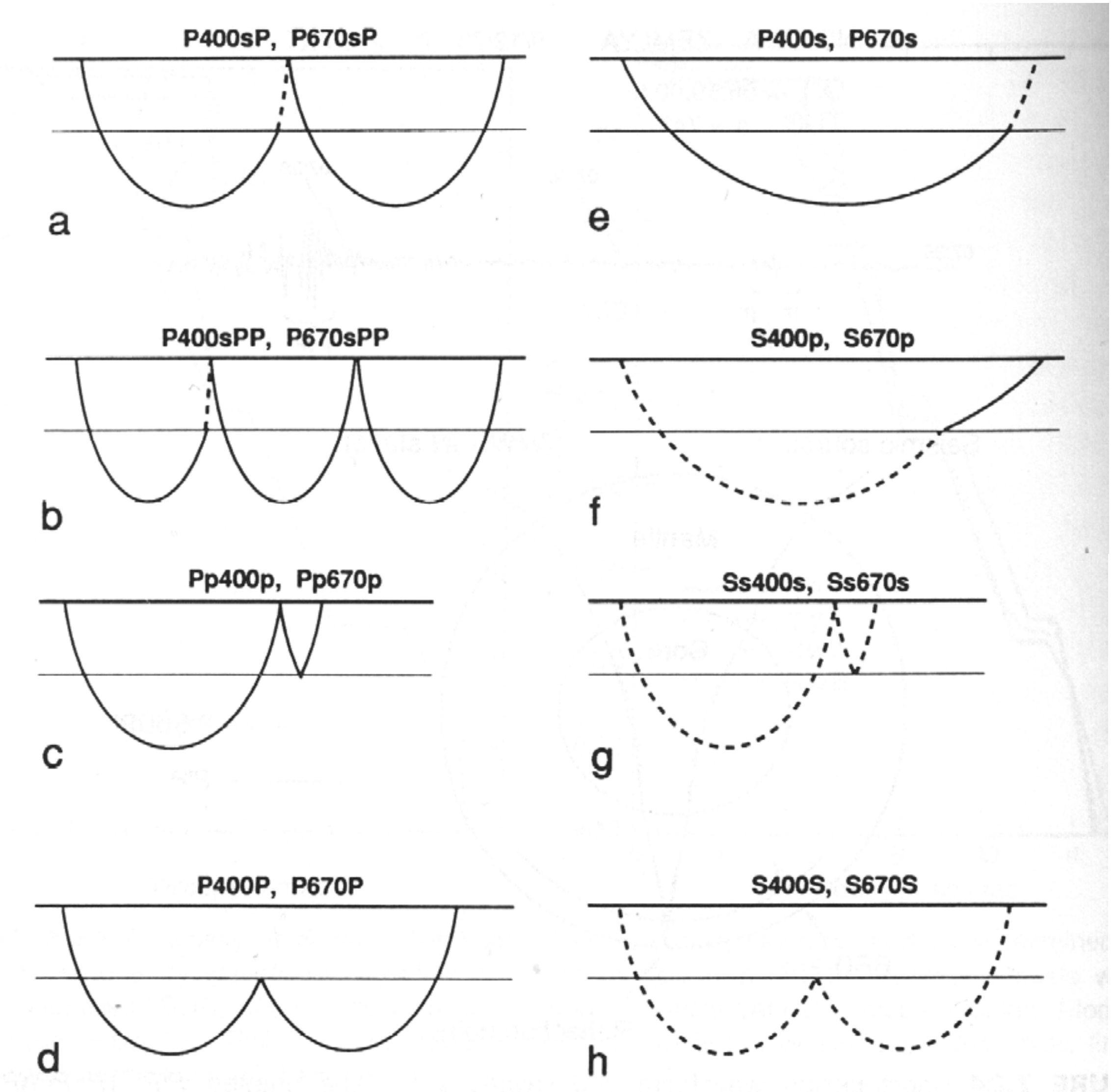


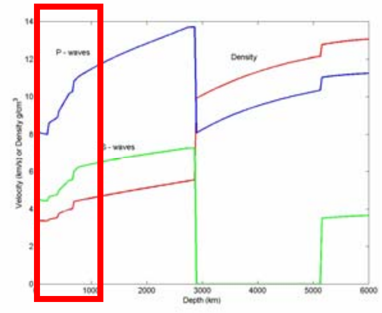


Various upper mantle seismic models and experimental results for minerals and mineral assemblages.

Upper Mantle: Discontinuities

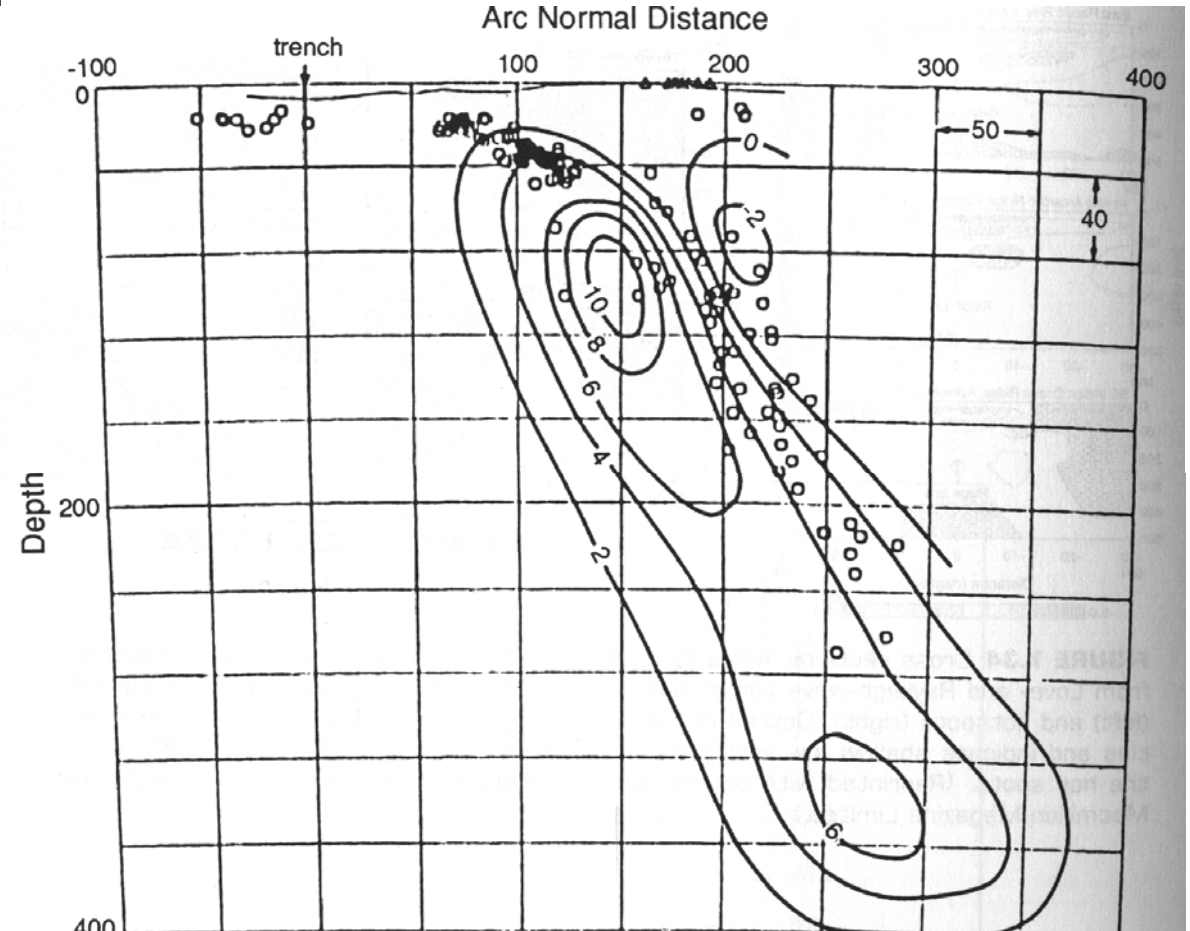


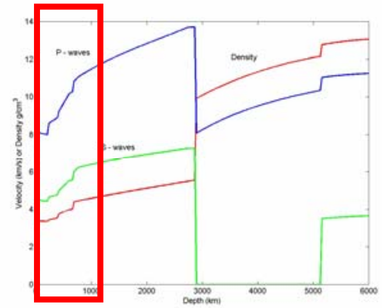




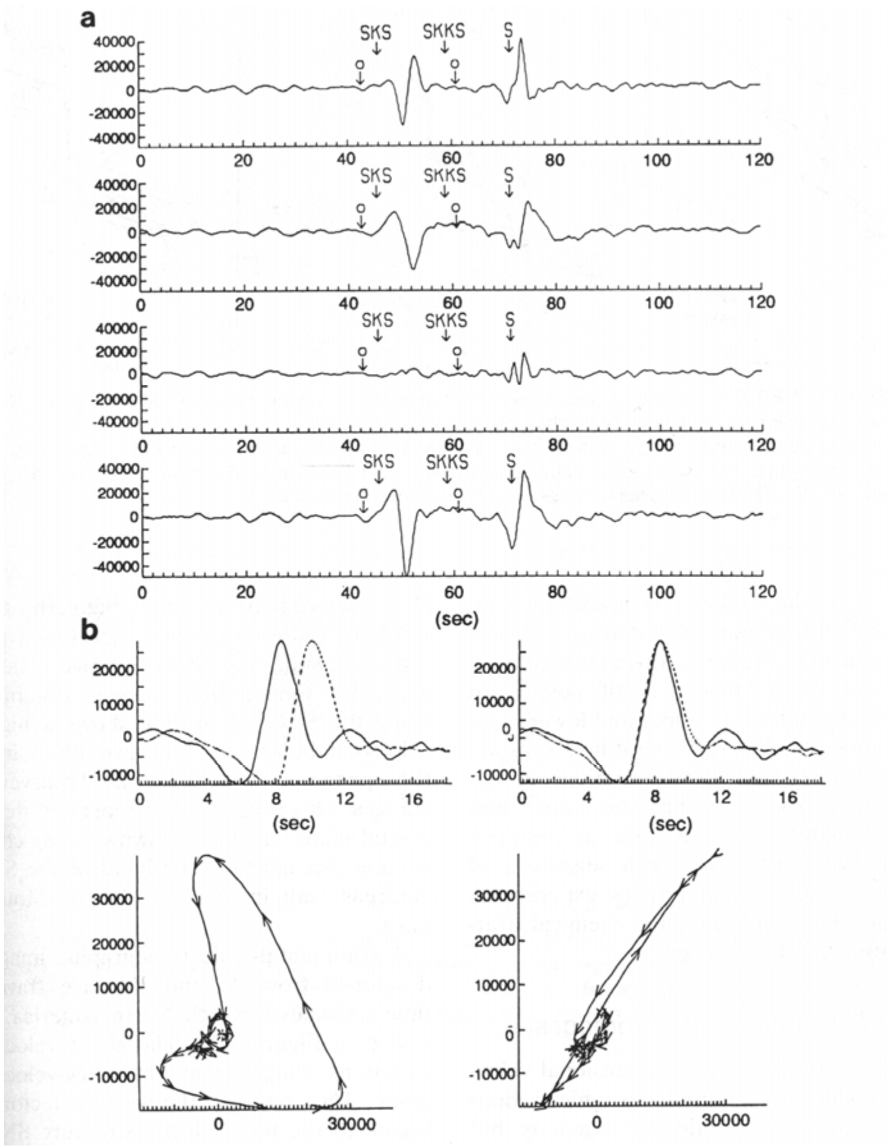
Various reflections from upper mantle discontinuities are being used to investigate the structural details of the transition zones (e.g. vertical gradients, thickness of transition zone, topography of discontinuities, etc.)

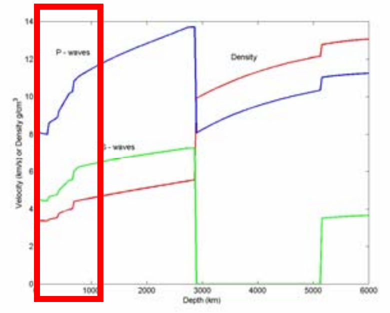
Upper Mantle: Phase transitions





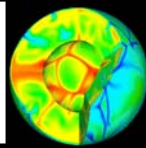
The location of seismic source within high velocity anomalies indicates downgoing slab structures. Where do earthquakes seem to happen preferentially?

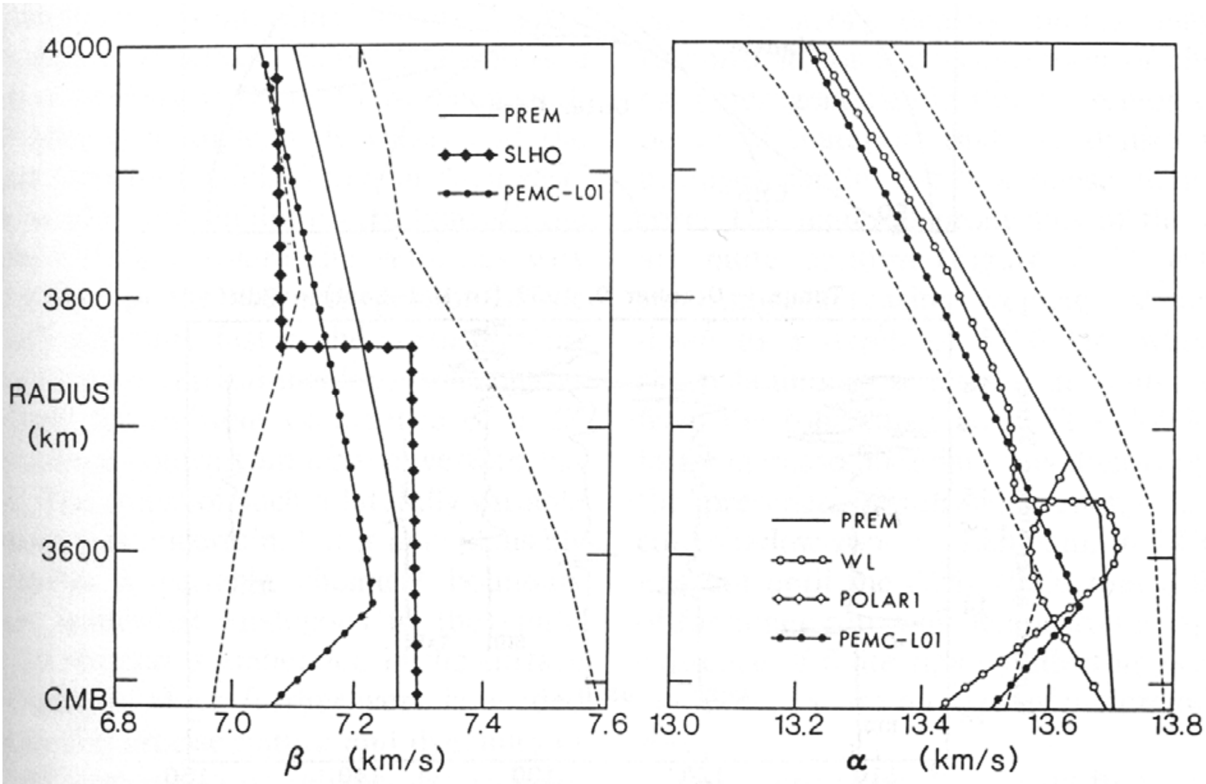


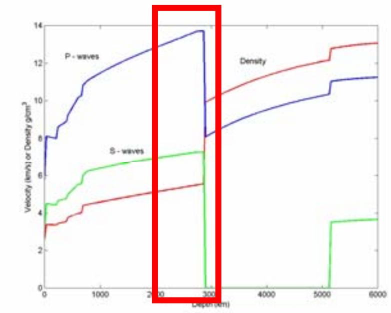


Shear wave splitting of the SKS phase indicates seismic anisotropy in the upper mantle. The alignment of the anisotropic symmetry system is thought to be correlated with tectonic plate motion.

Lower Mantle: D”

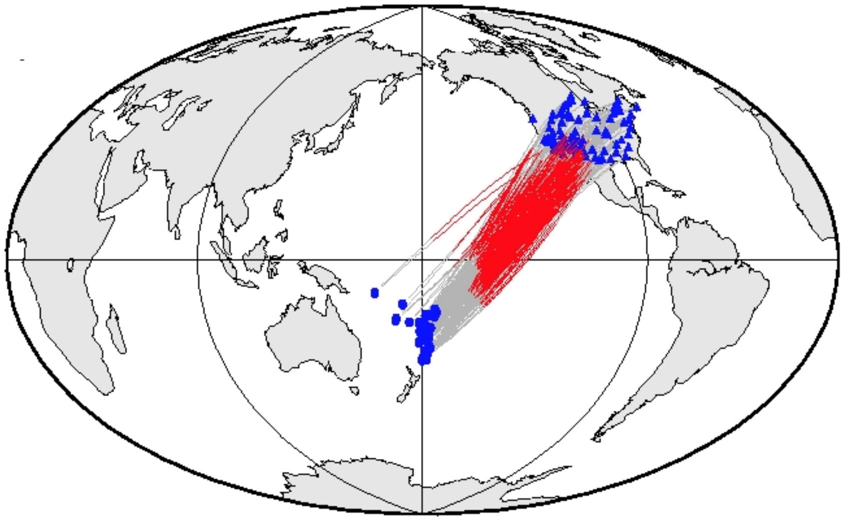


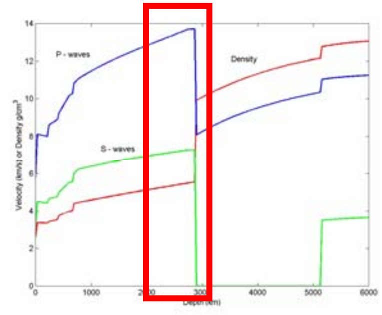




The mid-mantle shows little lateral heterogeneity. The lowermost mantle (D”) hast strong (possibly >10%) lateral velocity perturbations. The may originate in a thermal boundary layer or from subducted lithosphere.

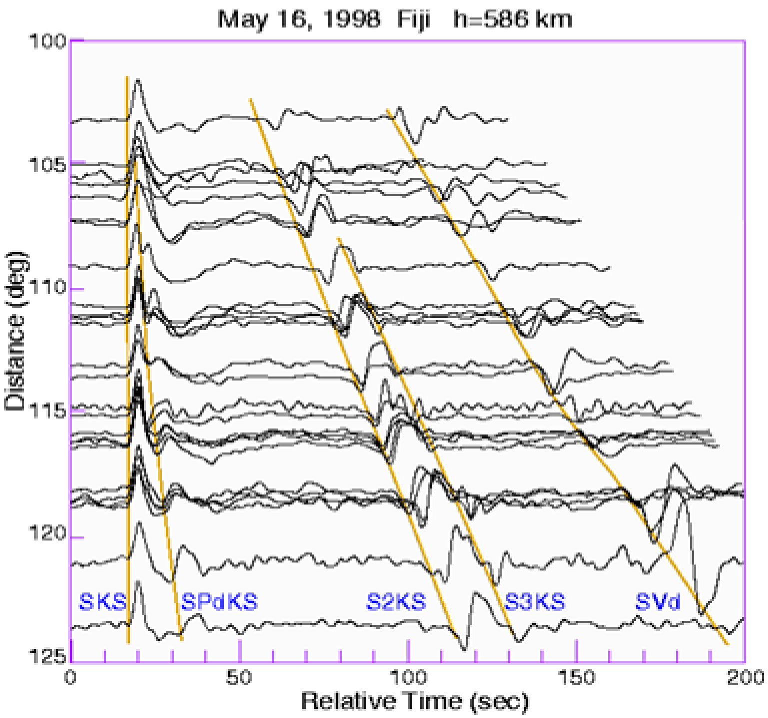
Lower Mantle: Diffracted Waves



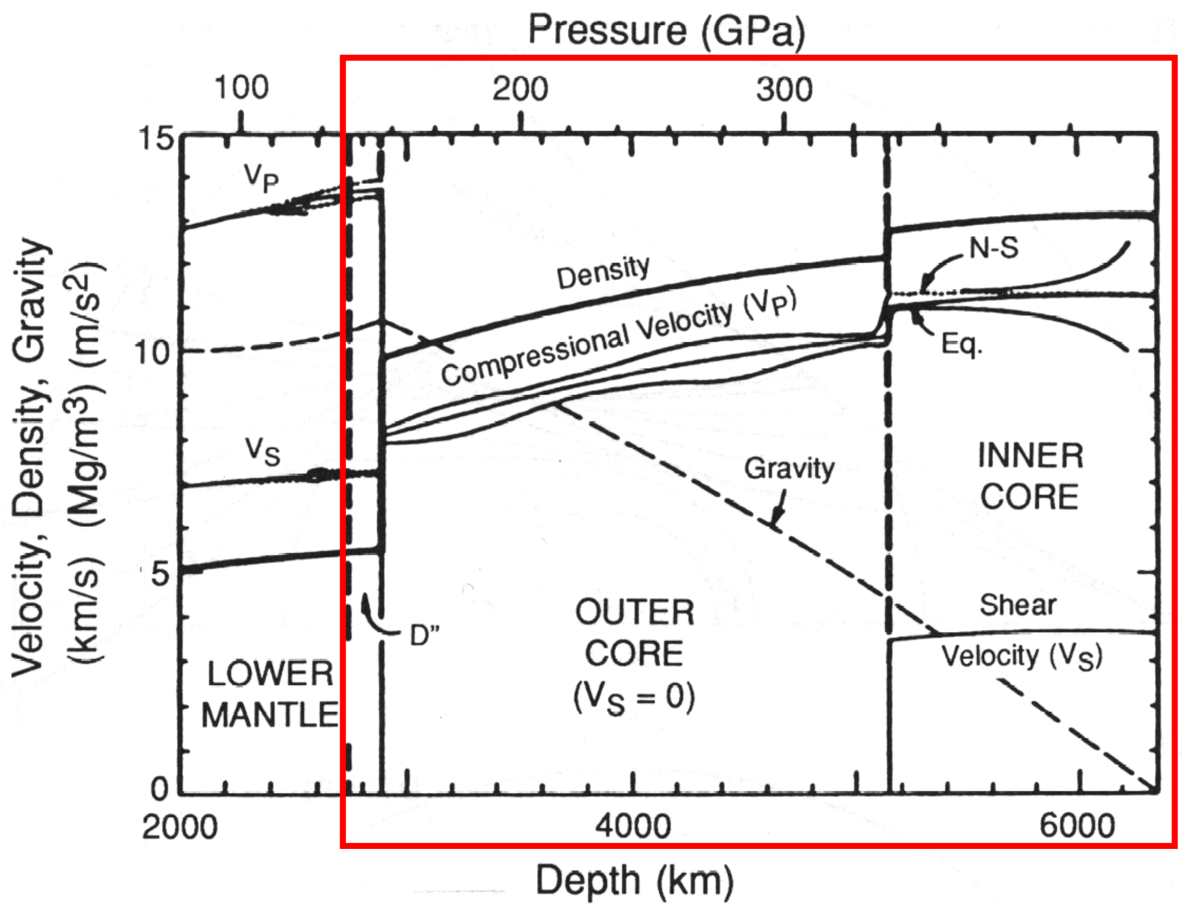


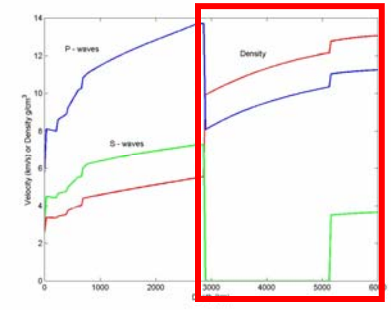
The lowermost mantle structure can be studies using waves diffracted at the core-mantle boundary.

Fiji-Tonga Broadband Data



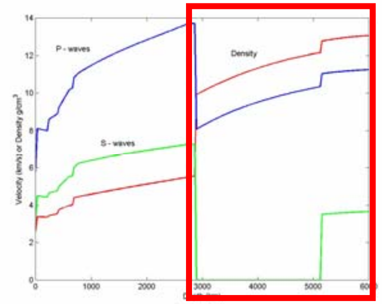
The Earth's Core

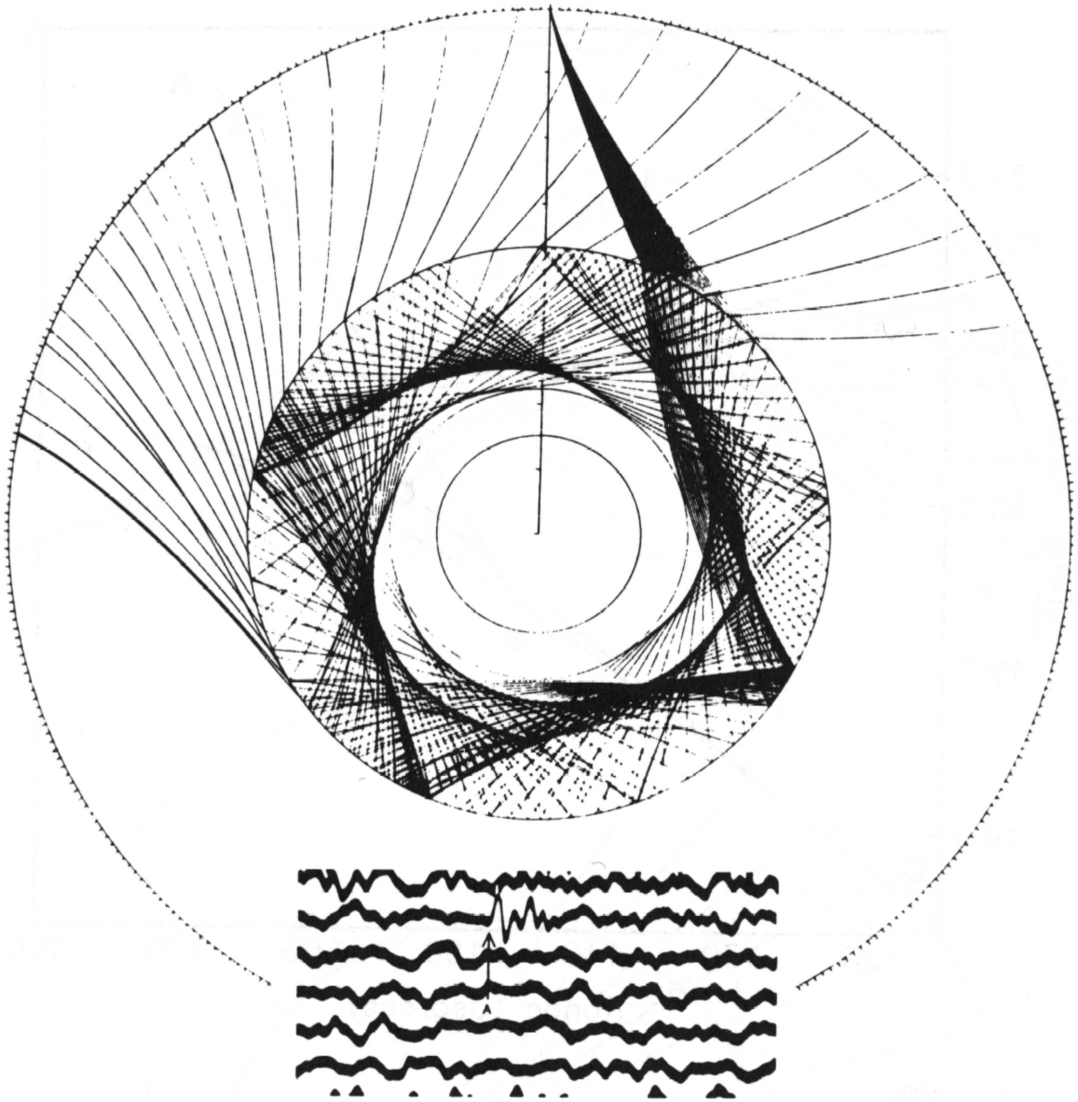




The Earth's inner core shows considerable anisotropy. Time-dependent differential travel times have led to the speculation that the Earth's inner core is rotating faster than the mantle.

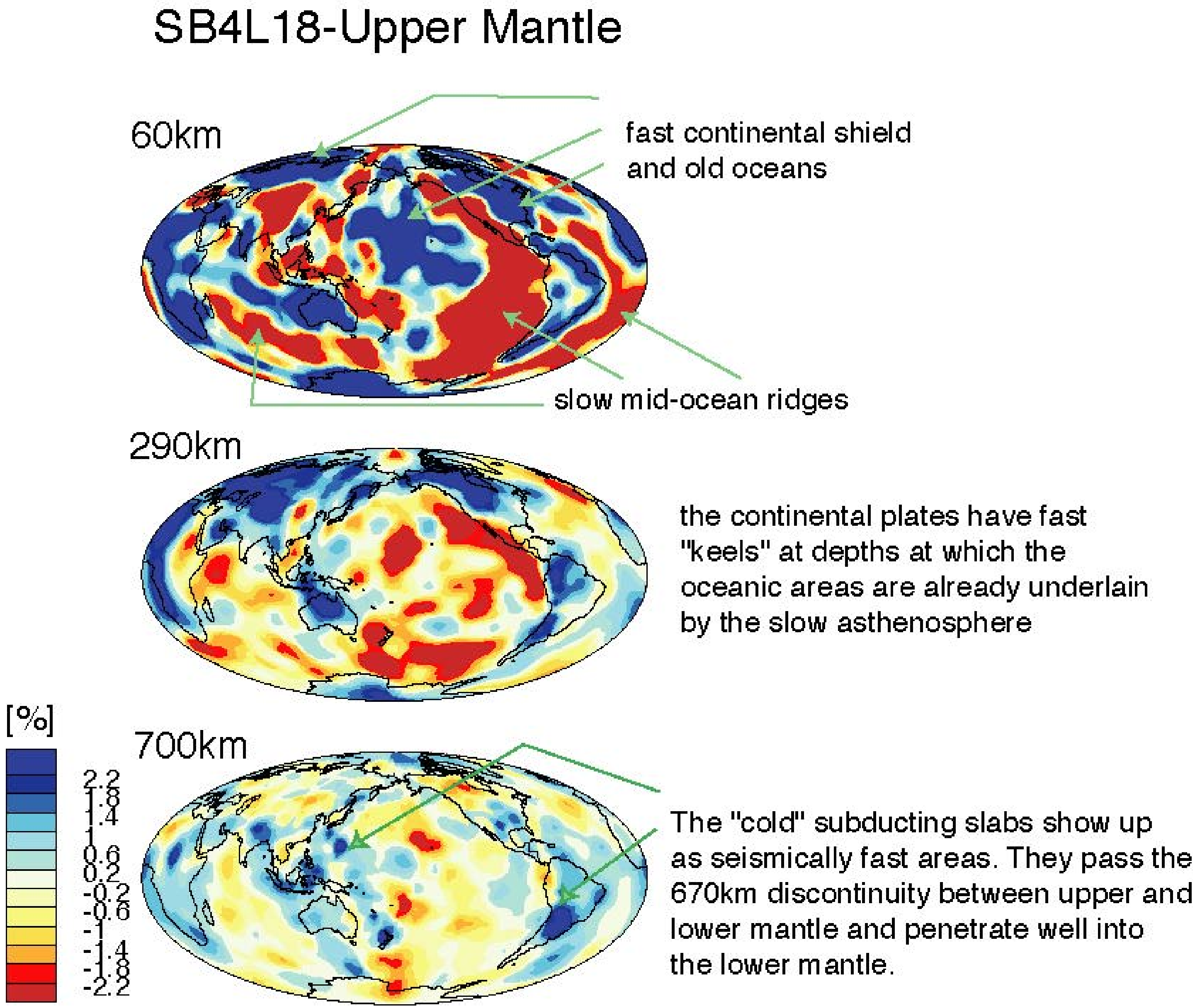
The Earth's Core: Multiples





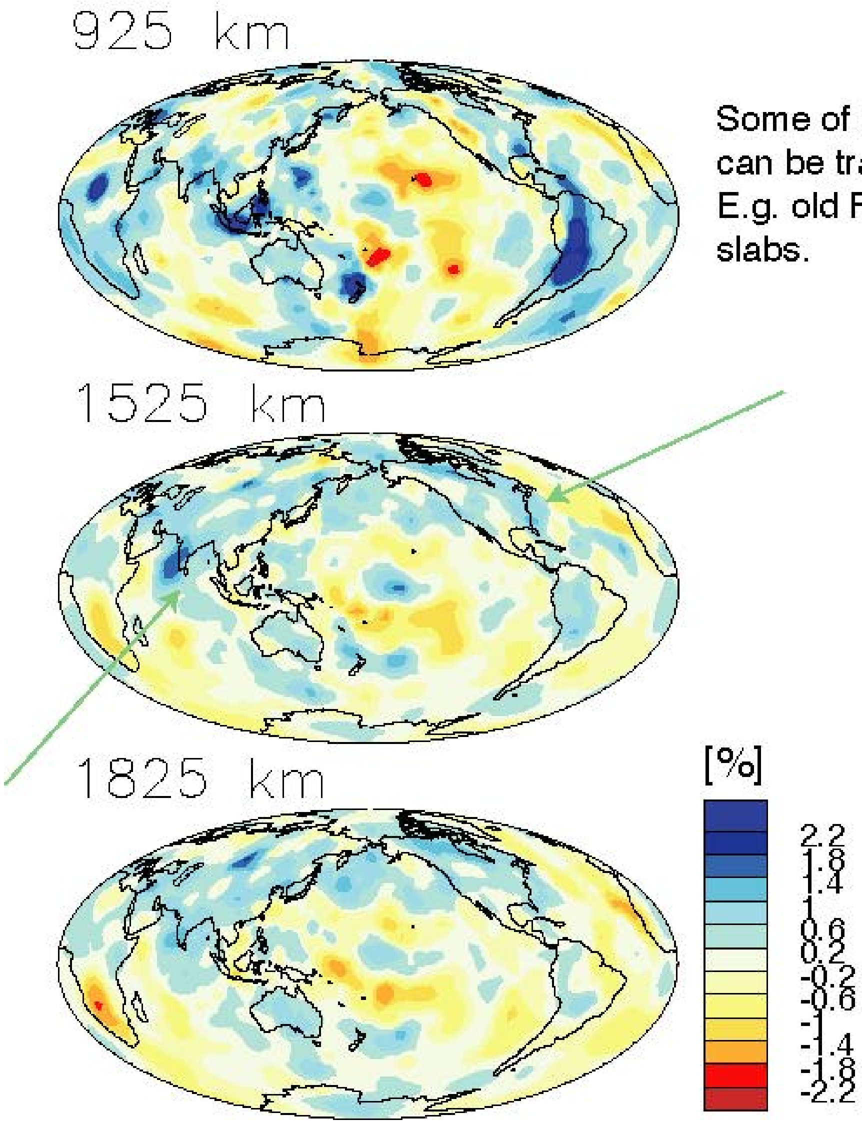
Multiple reflection ray paths PK_nP in the outer core and recording of PK_4P from an underground nuclear explosion.

Upper mantle: 3-D structure



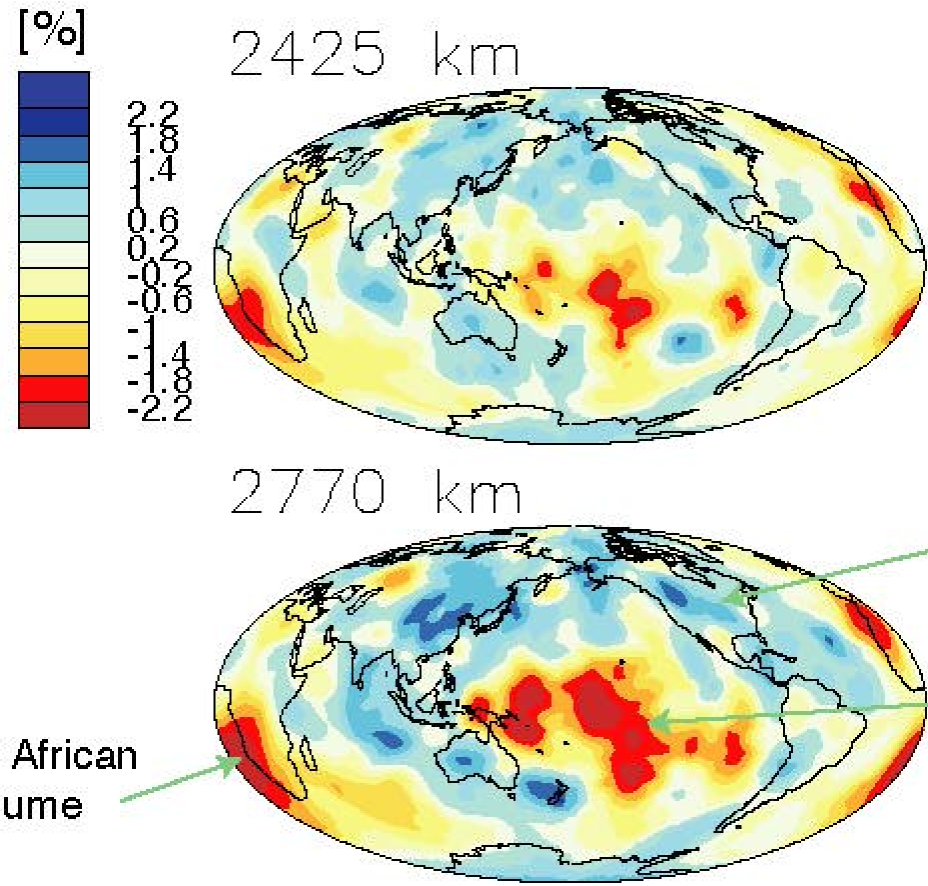
Mid-mantle: 3-D structure

SB4L18-Mid-Mantle



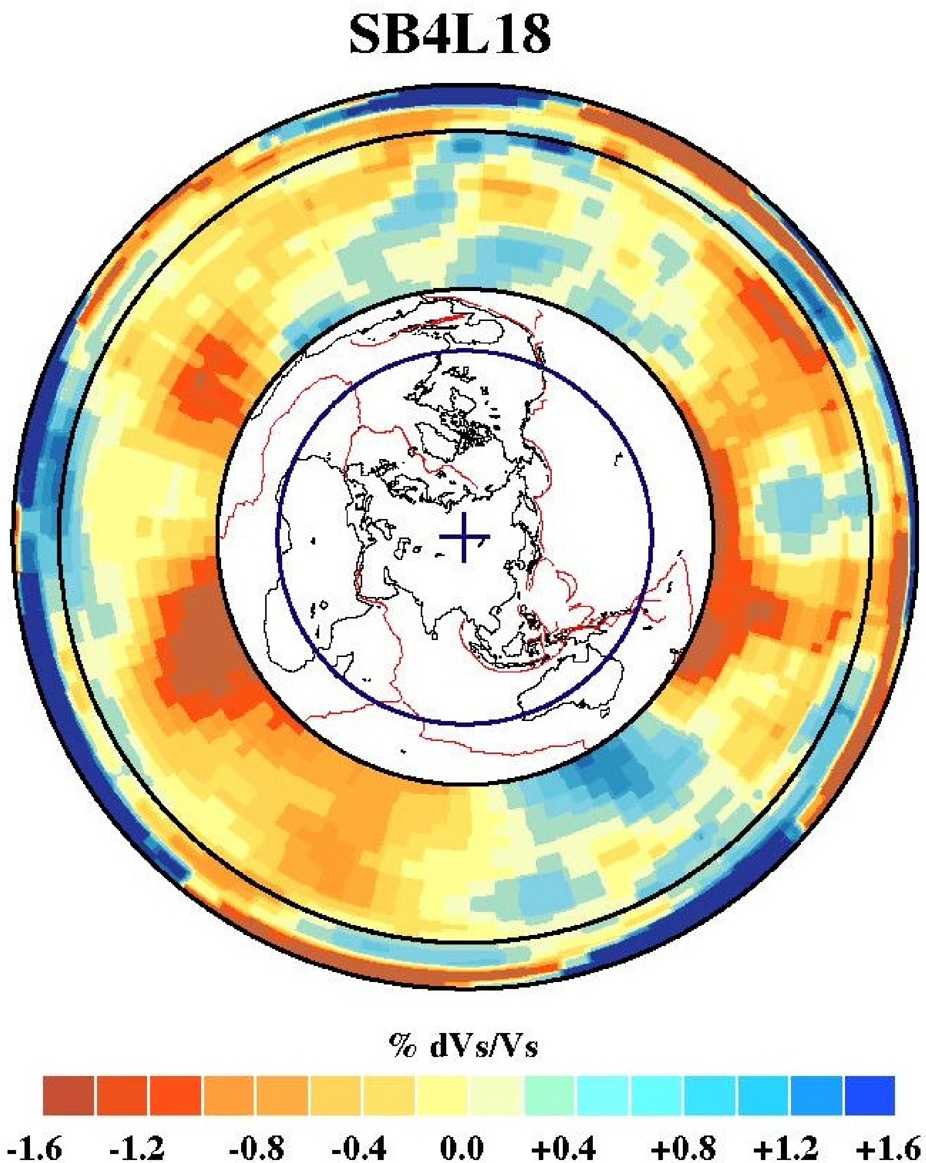
Some of the "cold" subducting slabs can be traced well into the lower mantle. E.g. old Farallon and Tethian subducting slabs.

SB4L18-Lowermost Mantle

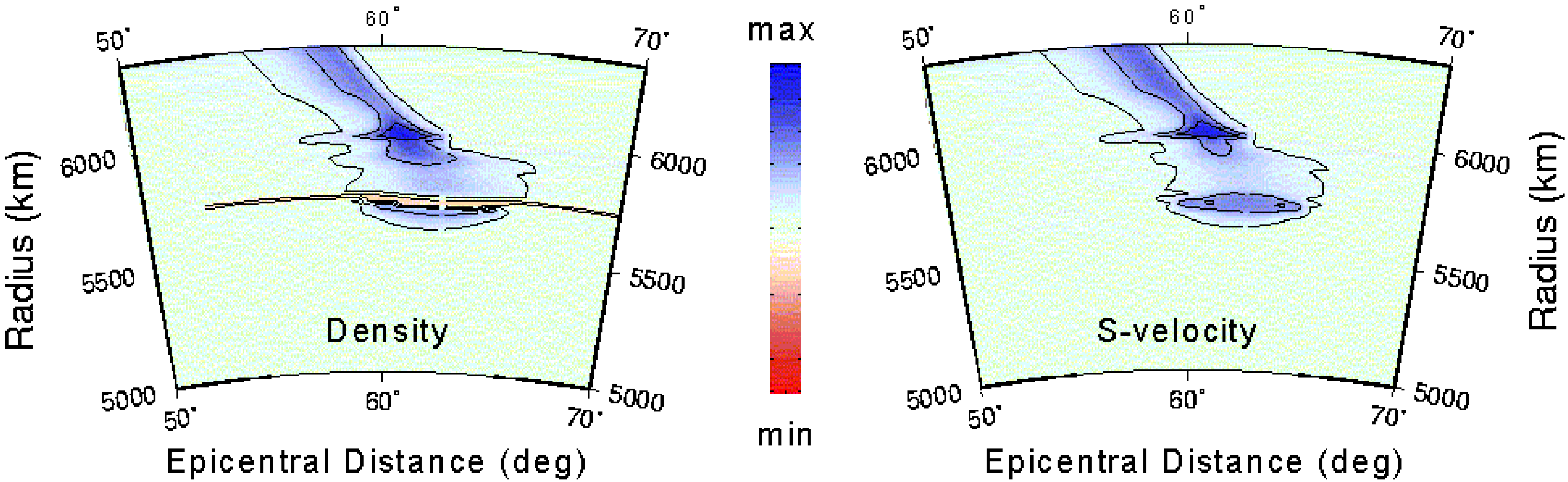


The lowermost mantle is dominated by a ring of "fast" material around the Pacific and "slow" material in the Central Pacific and beneath Africa. The fast regions are thought to be the "graveyard of subducting slabs".

Global Cut: 3-D structure

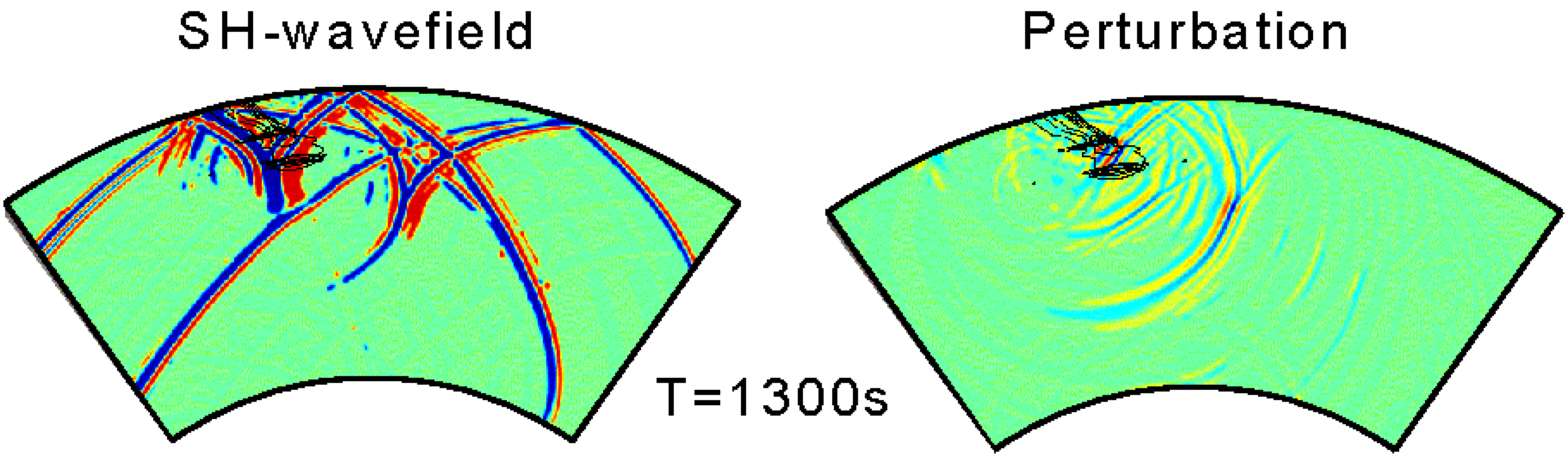


Geodynamic Modelling: Subduction Zones



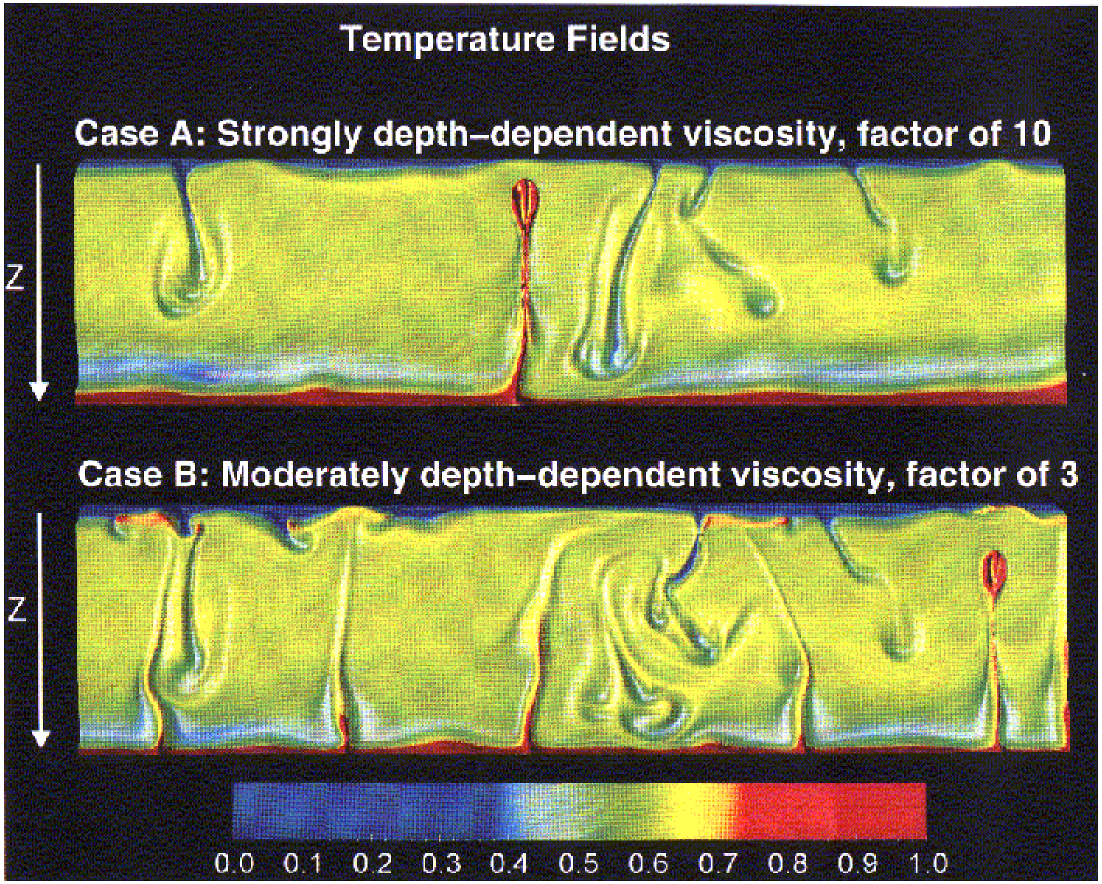
Perturbation of seismic velocity and density for a subducting plate obtained from numerical convection modelling including phase transitions.

Geodynamic Modelling: Subduction Zones



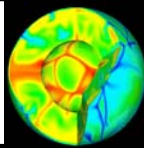
Snapshots through subducting slab model and the wavefield perturbation due to the slab. The background model is PREM.

Geodynamic Modelling: Plumes



High-resolution numerical study of plumes and the effects of the mantle viscosity structure.

The Earth’s Structure: Summary



The Earth’s seismic velocity structure can be determined from inverting seismic travel times (e.g. using the Wiechert-Herglotz technique for spherically symmetric media).

The Earth’s radial structure is dominated by the core-mantle boundary, the inner-core boundary, the upper-mantle discontinuities (410km and 670km) and the crust-mantle transition (Moho).

The 3-D structure of the Earth’s interior can be determined by inverting the travel-time perturbations with respect to a spherically symmetric velocity model (e.g. PREM). The positive and negative velocity perturbations are thought to represent cold (dense) or hot (buoyant) regions, respectively.

There is remarkable correlation between fast regions and subductin zones as well as slow regions with hot-spot (plume) activity.