Seismic processing using SAC

0.0 An introduction to seismology

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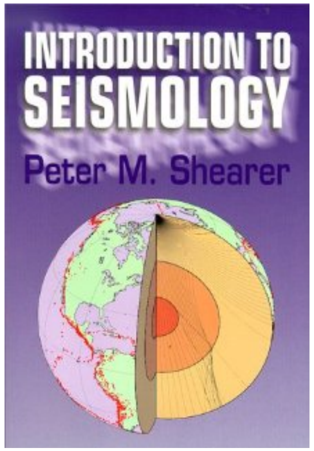
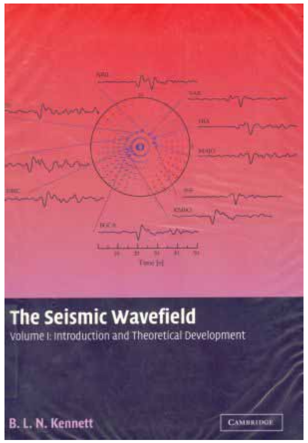
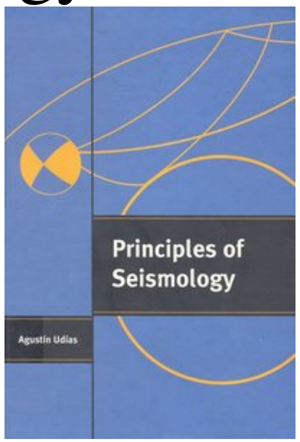
Suggested Textbooks

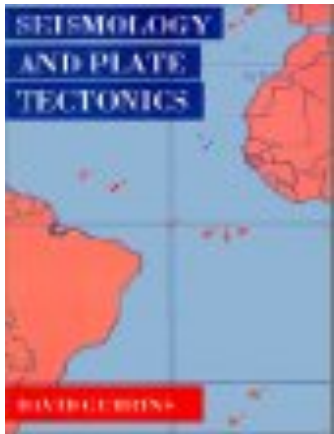
Introductory Texts:

- Shearer (2009) - Introduction to Seismology, 2nd Ed.
- Kennett (2002) - The Seismic Wavefield: Introduction and Theoretical Development.
- Bullen and Bolt (1985) - An Introduction to the Theory of Seismology, 4th Ed.
- Udias (1999) - Principles of Seismology.
- Gubbins (1990) - Seismology and Plate Tectonics.





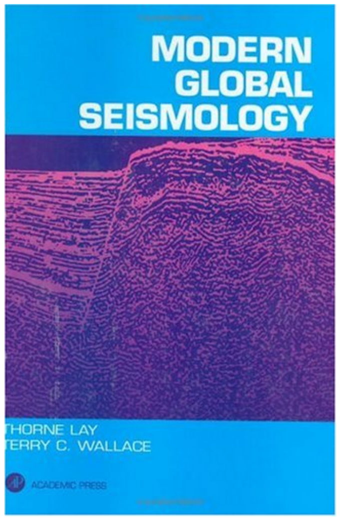


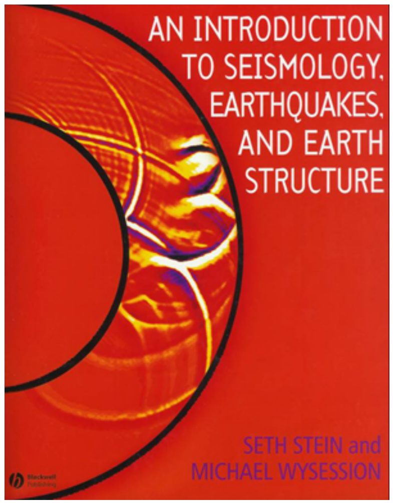


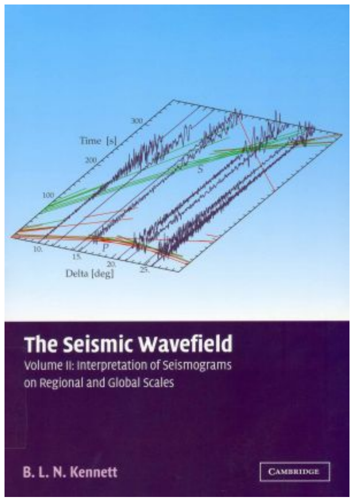
Suggested Textbooks

Observational Global Seismology:

- Lay and Wallace (1995) - Modern Global Seismology
- Stein and Wysession (2003) - An Introduction to Seismology, Earthquakes and Earth Structure.
- Kennett (2002) - The Seismic Wavefield: Interpretation of Seismograms on Regional and Global Scales







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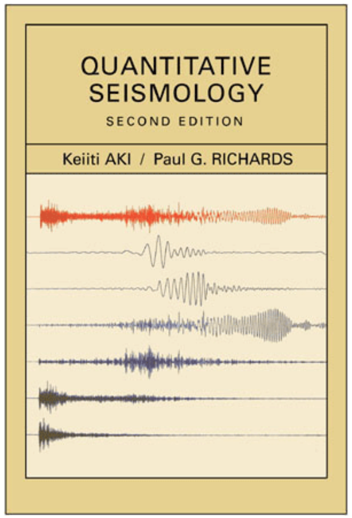
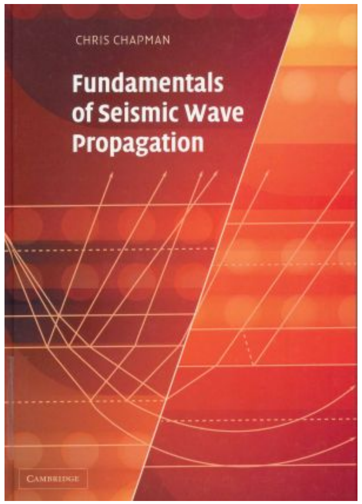
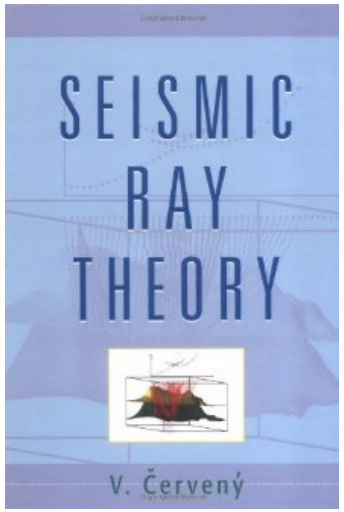
Suggested Textbooks

Theoretical Seismology:

- Aki and Richards (2002) - Quantitative Seismology, 2nd Ed.
- Chapman (2004) - Fundamentals of Seismic Wave Propagation.
- Cerveny (2001) - Seismic Ray Theory.
- Dahlen and Tromp (1998) - Theoretical Global Seismology.







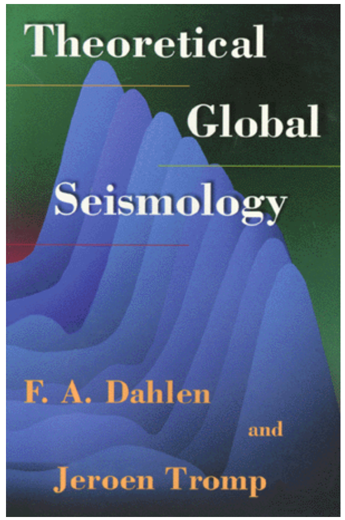


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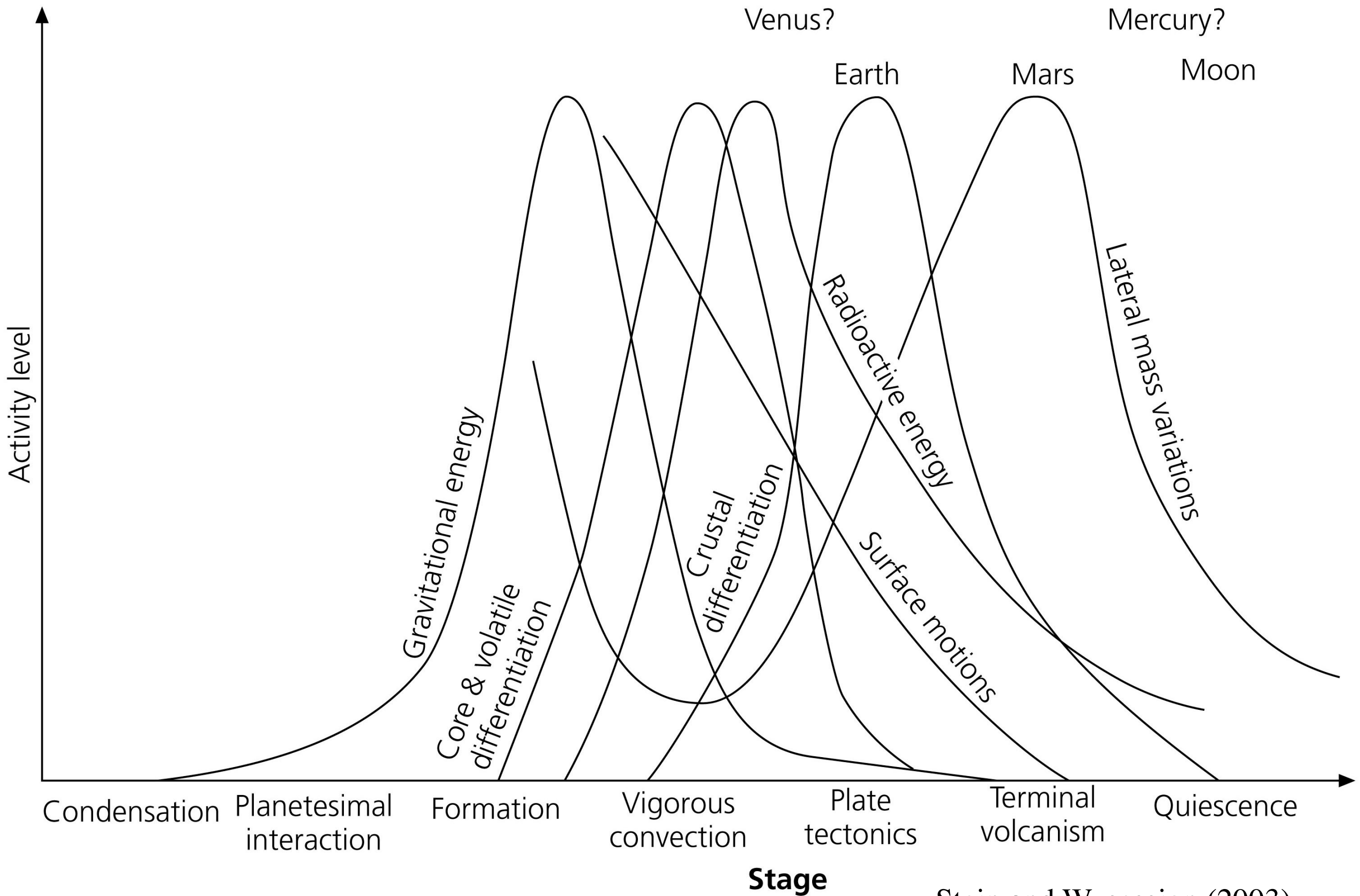
Plate tectonics:
A unique feature of Earth?
The Goldilocks planet.

Figure 3.8-16: Model for the evolution of terrestrial planets.



Stein and Wysession (2003)

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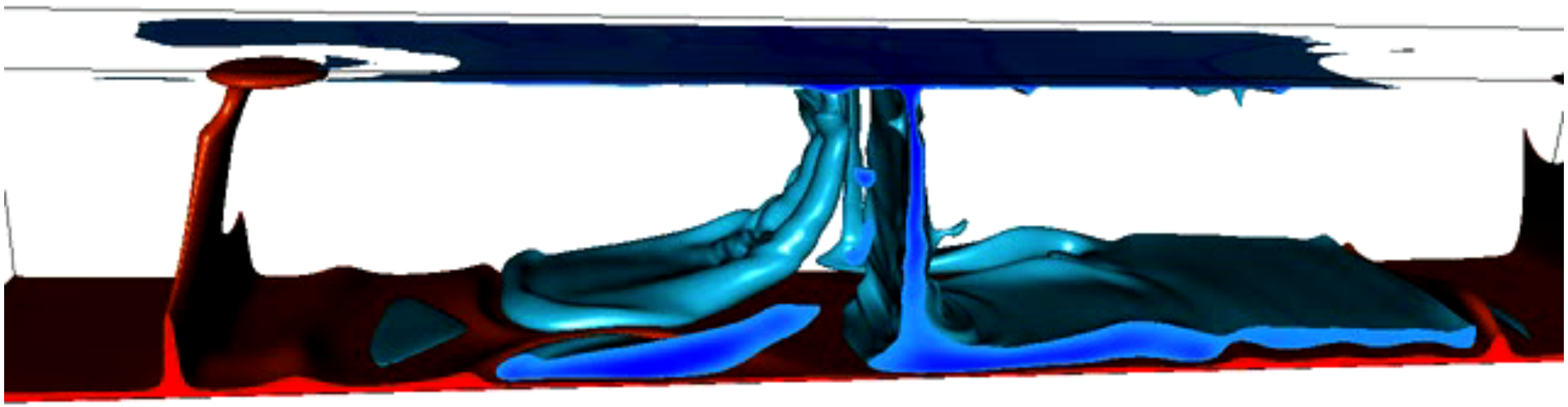
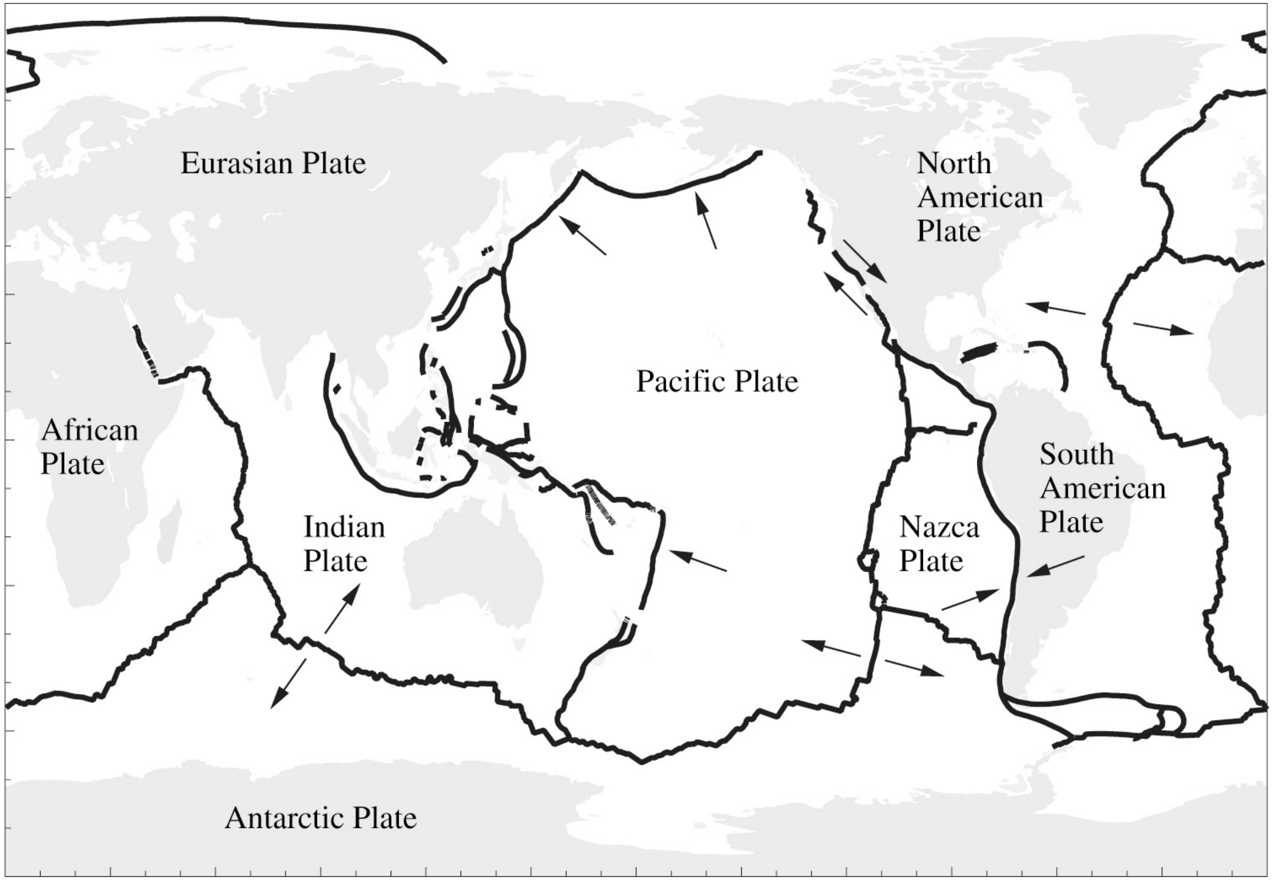


Courtesy of J. Lowman

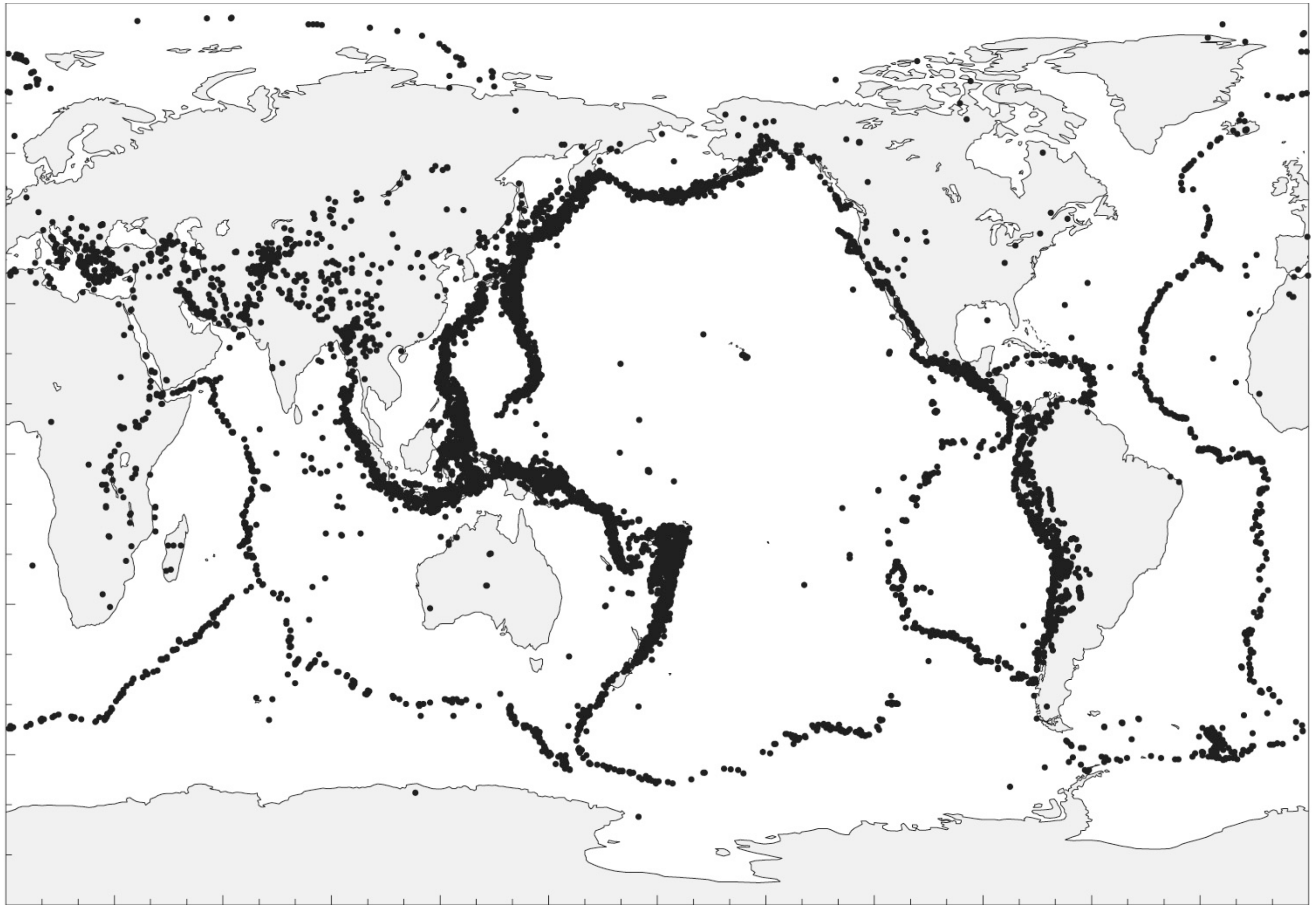
Tectonic Plates



Shearer (2009)

3 types of plate boundaries

Earthquake locations



Shearer (2009)

Earthquakes from 1977-1994.

Occur primarily along plate boundaries.

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Seismicity also delineates boundaries at depth.

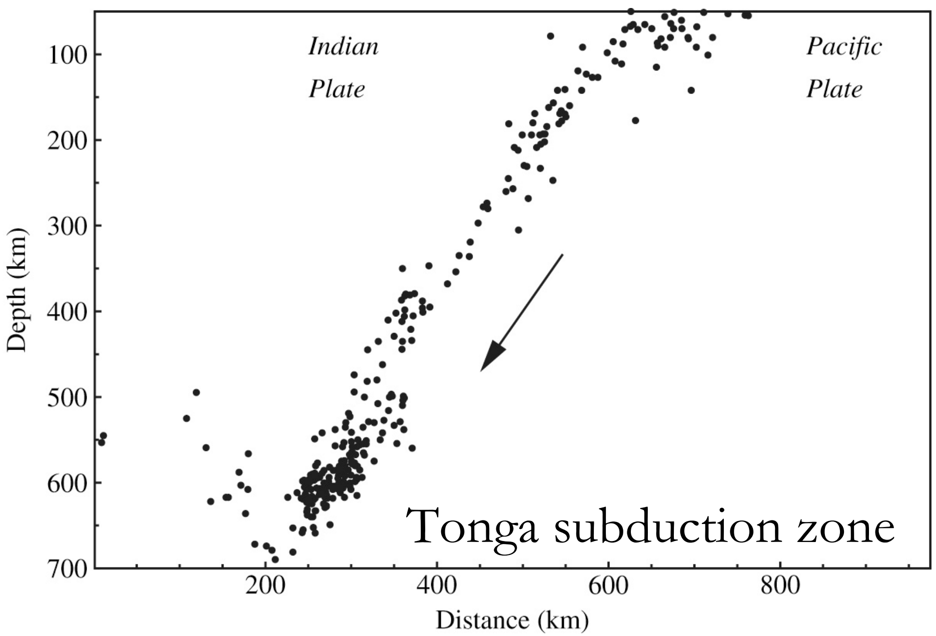
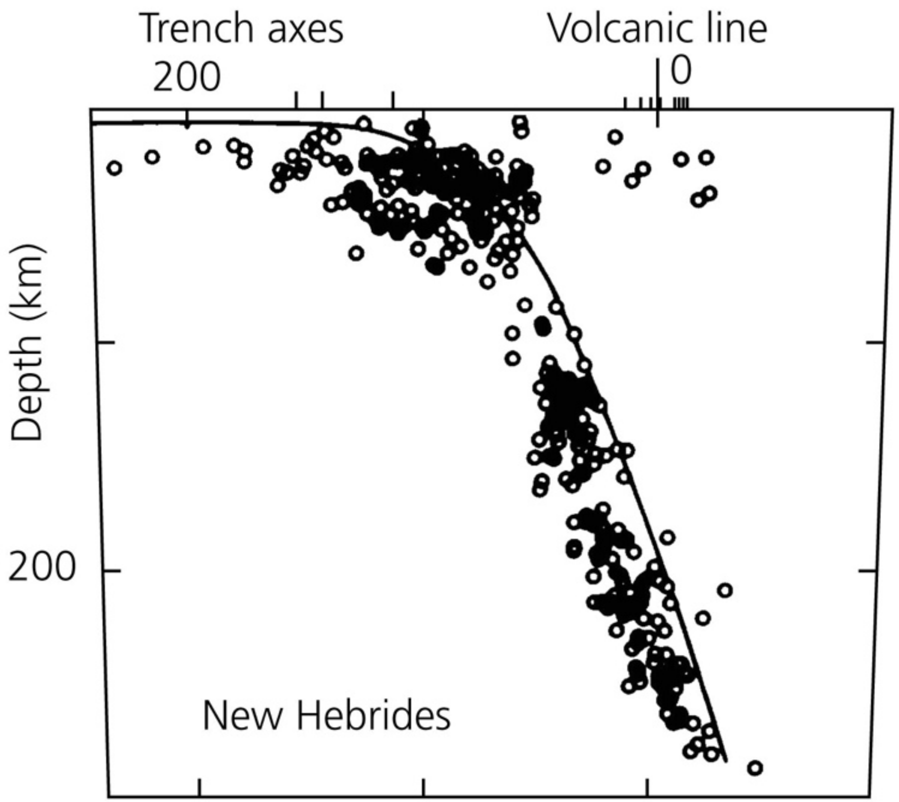


Figure 5.1-5: Seismicity cross-section of the New Hebrides trench.



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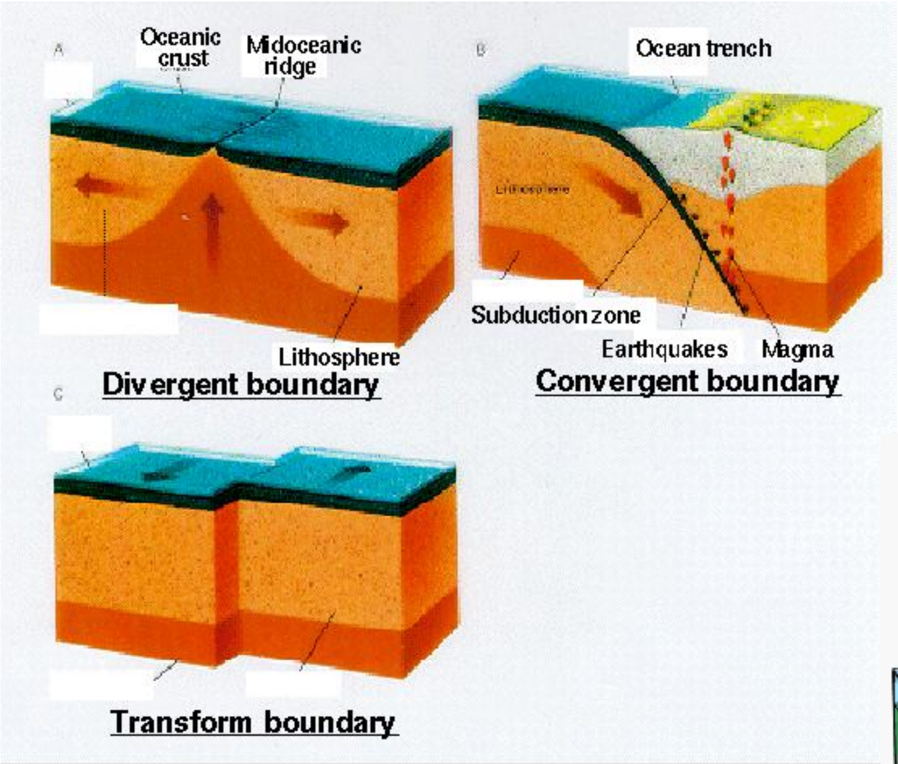
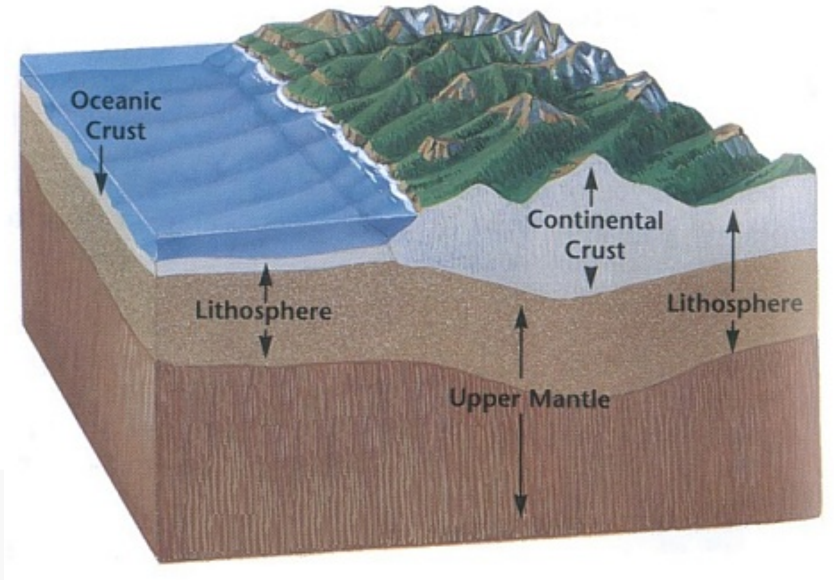
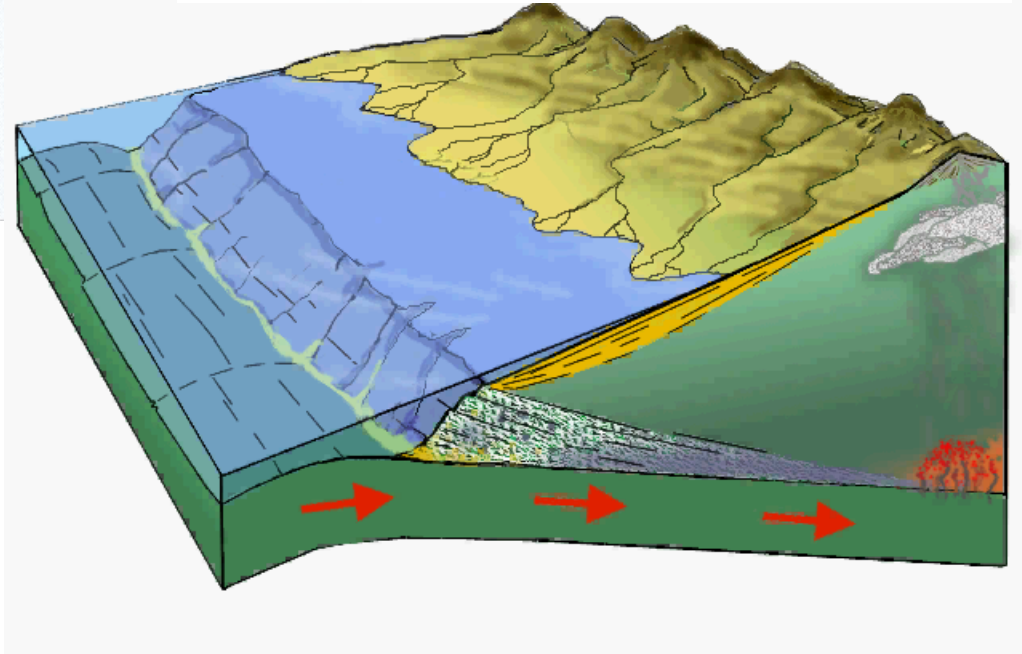
Earthquakes







3 types of plate boundaries

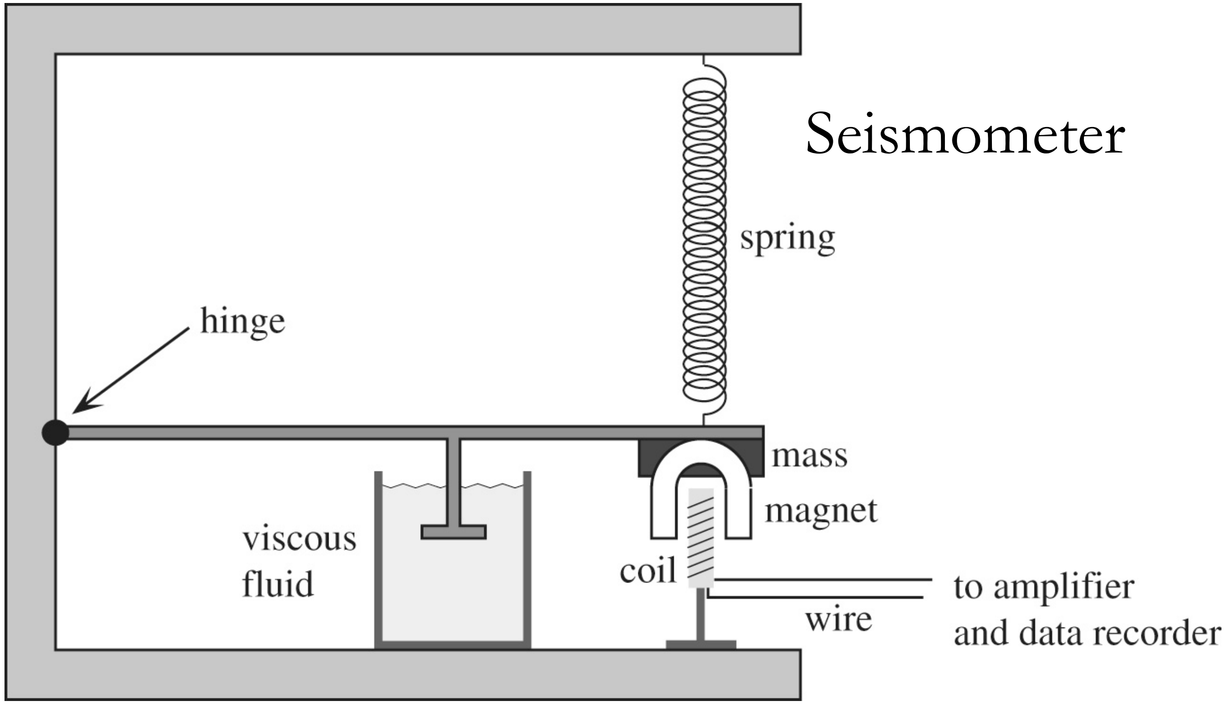
A Brief History of Seismology

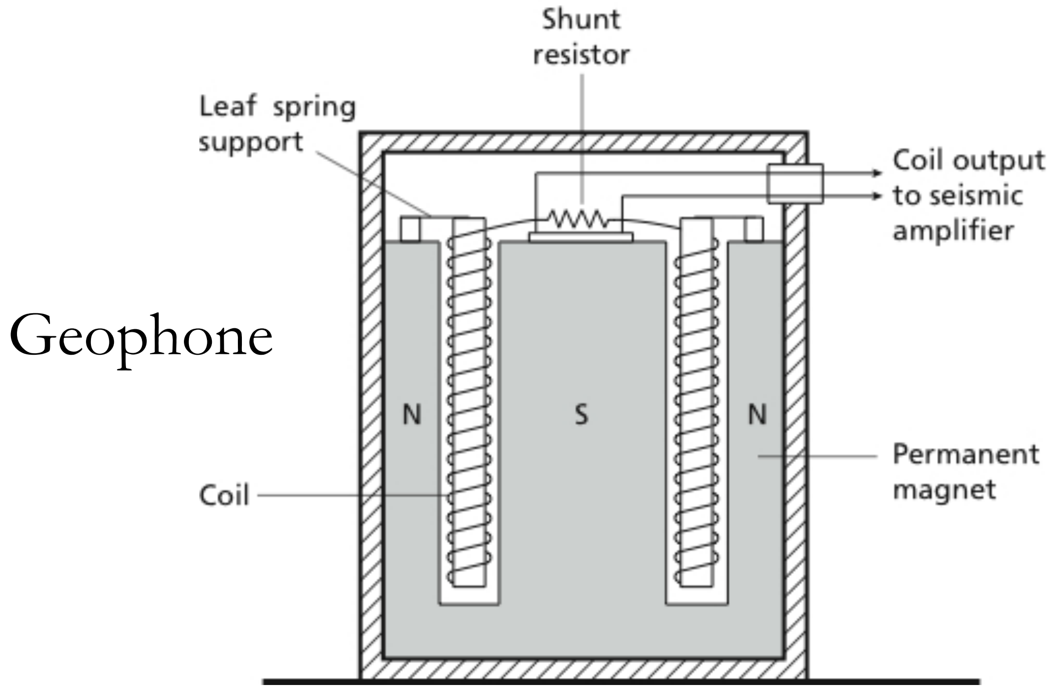
Theory:

- Cauchy, Poisson, Stokes, Rayleigh, Love (1800's).

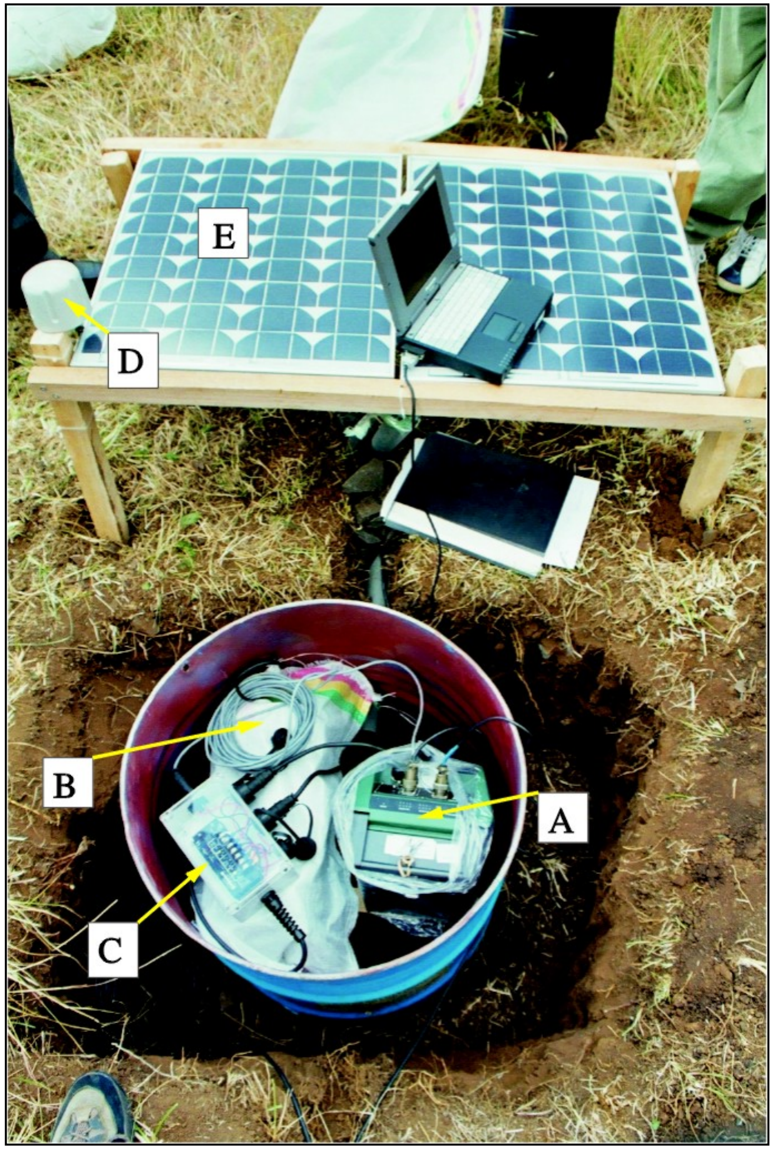
Instrumentation:

- 132 AD: Pendulum and mass, Zhang Heng (China)
- 1987: First time-recording seismograph, Filippo Cecchi (Italian).
- 1889: First oberservation of a teleseism (Japan event recorded in Potsdam).
- 1898: First seismomters with viscous damping (Weichert, Germany)
- 1880's: Milne, Ewing & Gray (UK working in Japan).
- 1900: First electromagnetic seismometer (Galitzen, Russia).


Seismometer
spring
hinge
mass
magnet
viscous
fluid
coil
to amplifier
and data recorder
wire


Shunt
resistor
Leaf spring
support
Coil output
to seismic
amplifier
Geophone
N
S
N
Permanent
magnet
Coil

Broadband seismic station



- A - SAM unit - Data Recorder
- B - Battery
- C - Regulator Box
- D - GPS
- E - Solar panels

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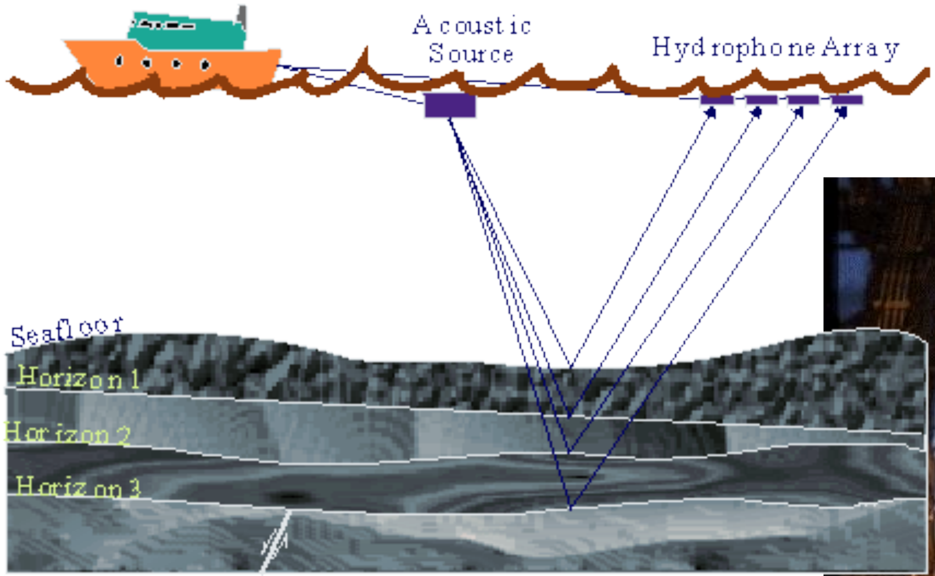
Seismic data acquisition

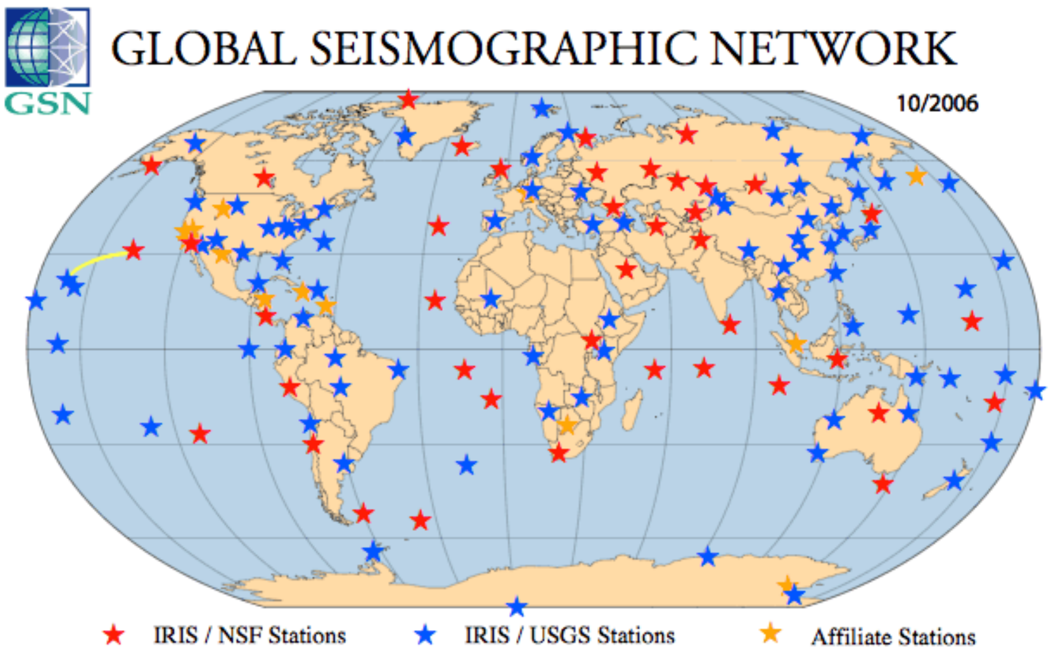
Seismic receivers: conversion of ground motion to an electrical signal. On land: geophones or seismometers. At sea: hydrophones and ocean-bottom seismometers.



Data explosion

1936

2006



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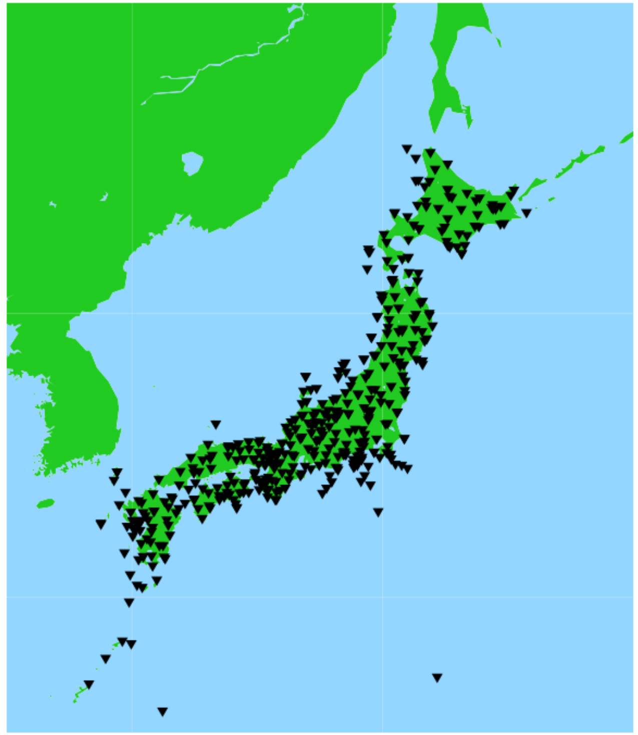
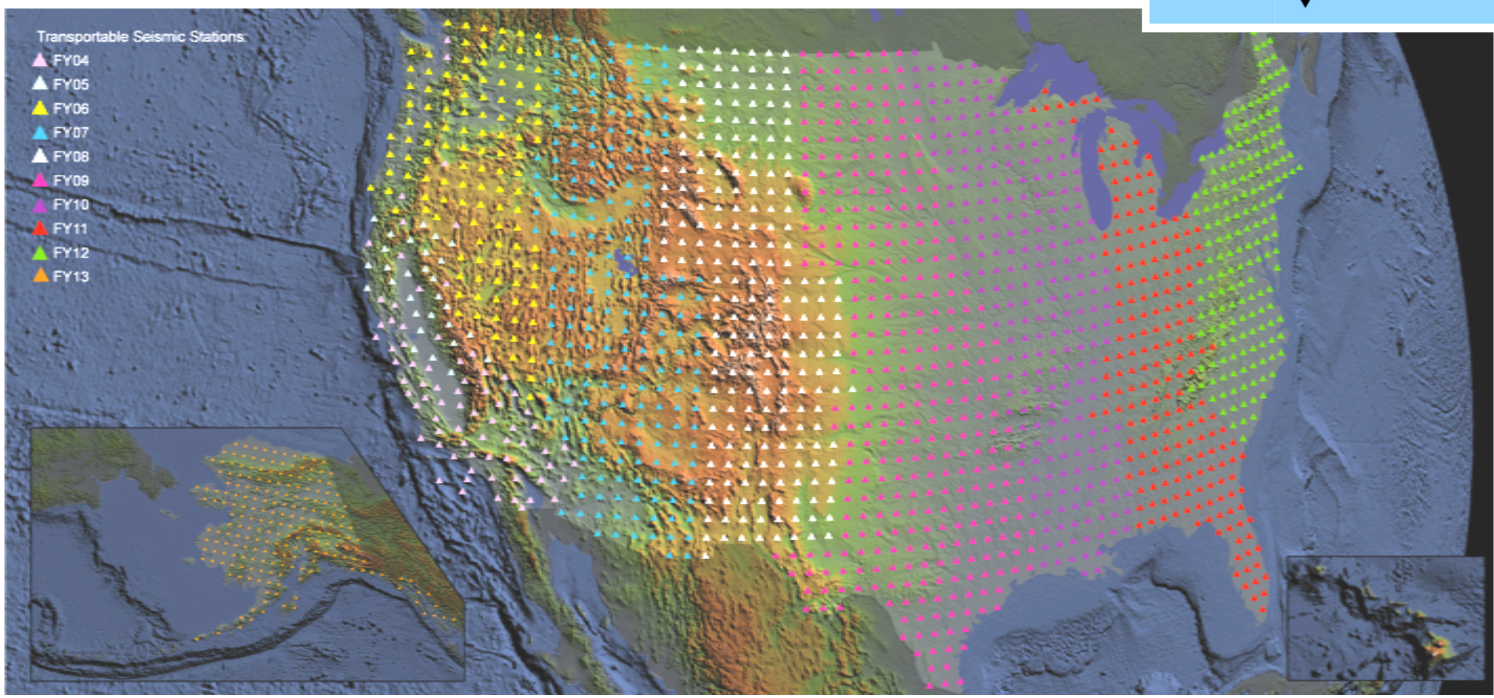
Data explosion

- H-Net; J-Array
- USArray





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A Brief History of Seismology

Imaging Earth's Velocity Structure from Seismograms:

- 1900: Oldham, P- and S-wave identified on seismograms.
- 1906: Oldham, recognised the Earth's core.
- 1909: Mohorovicic identified the crust/mantle bondary.
- 1907: Zoppritz, travel time tables (tt vs distance).
- 1914: Guttenberg, tt tables including core phases and CMB depth (2990).
- 1936: Lehmann, discovered the inner core.
- 1940: Jeffreys and Bullen travel time tables (many phases), led to JB Earth model.

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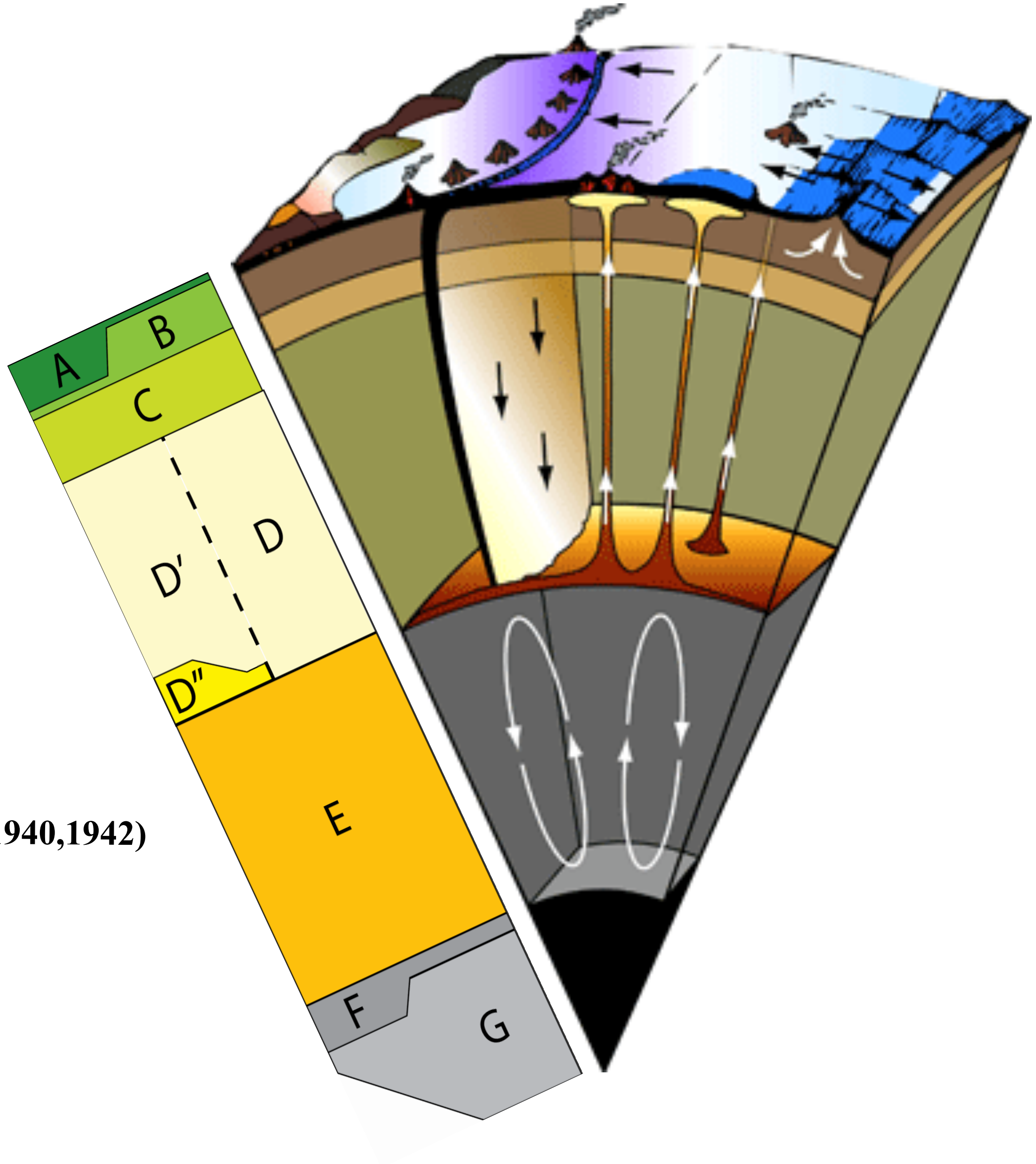

Bullen (1940,1942)

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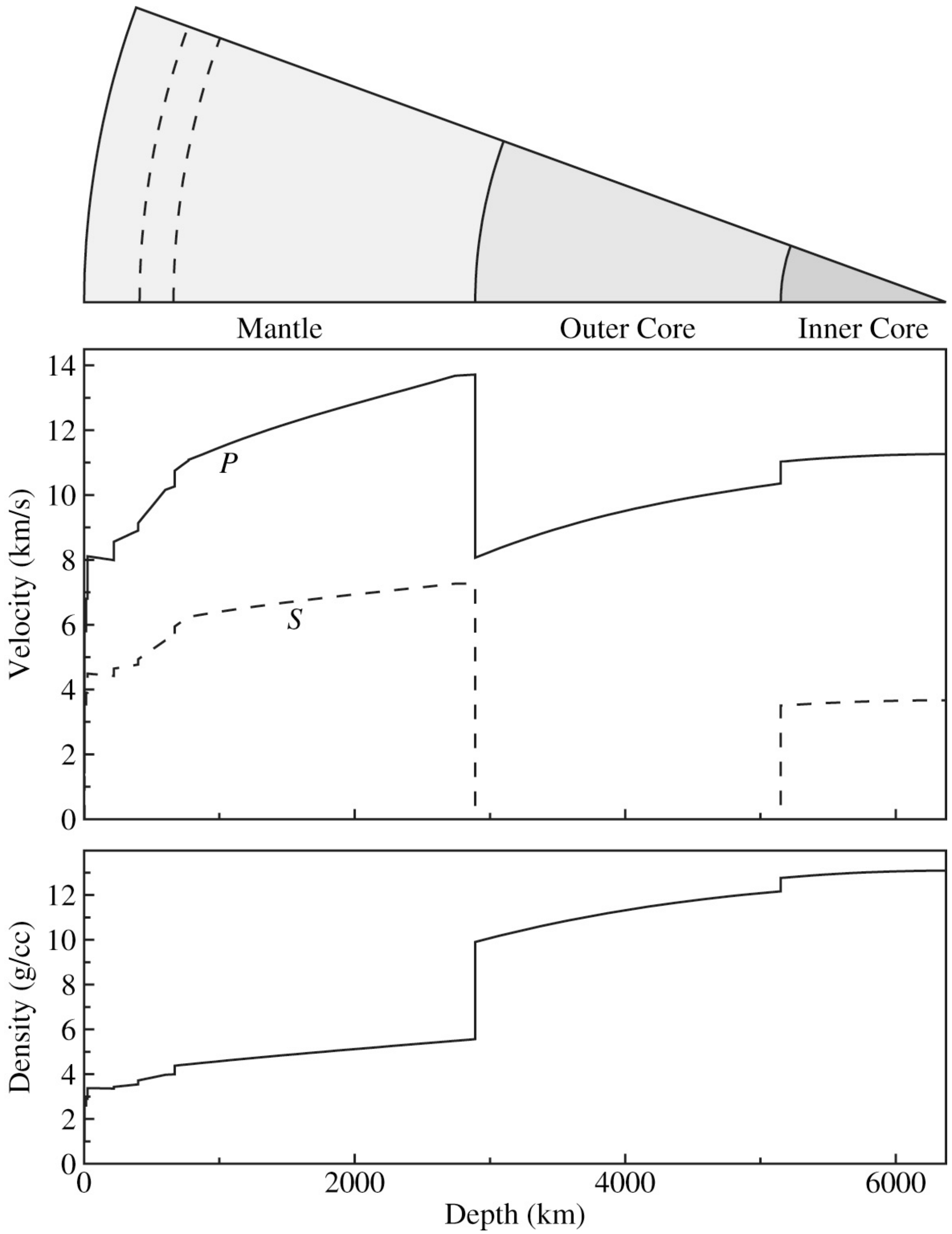

Mantle
Outer Core
Inner Core
Velocity (km/s)
P
S
Density (g/cc)
Depth (km)
0
2000
4000
6000

Earthquakes

- Source locations
- Source mechanisms

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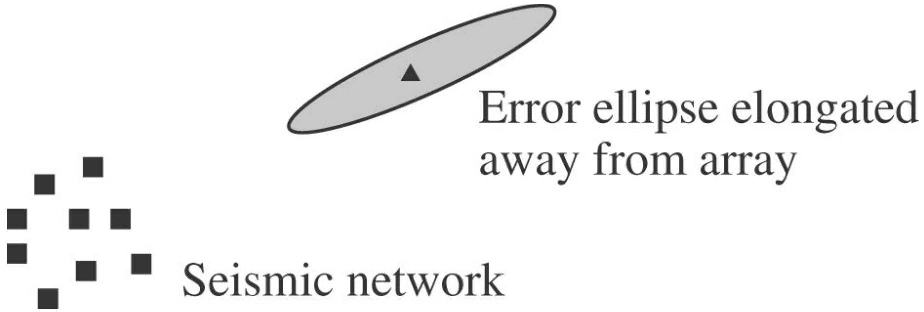
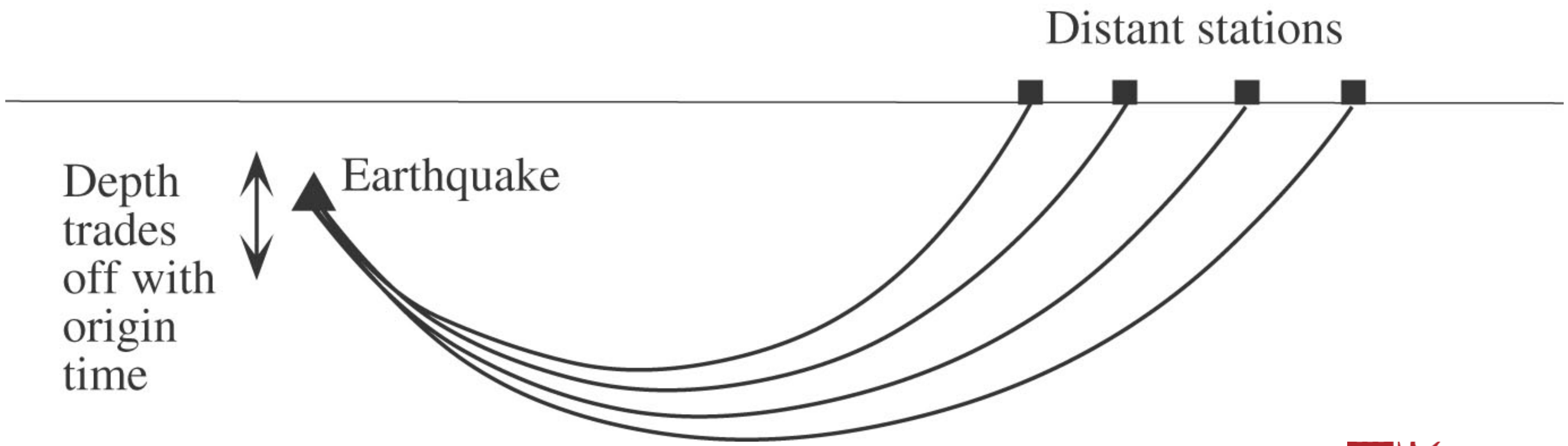
Earthquake Location

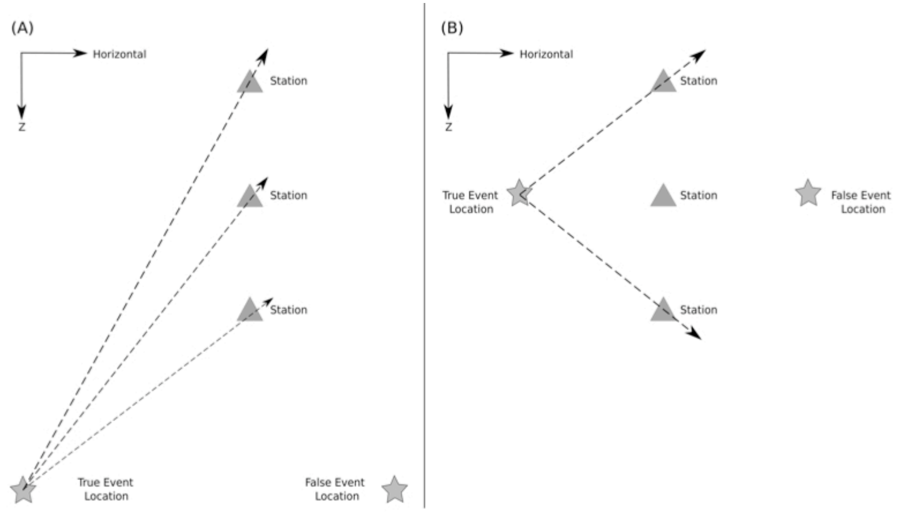
- Oldest challenge: origin time and hypocentre.
- $\boldsymbol{m} = (T, x, y, z)$
- n obserations of tts at individual stations; invert for m using reference Earth model.

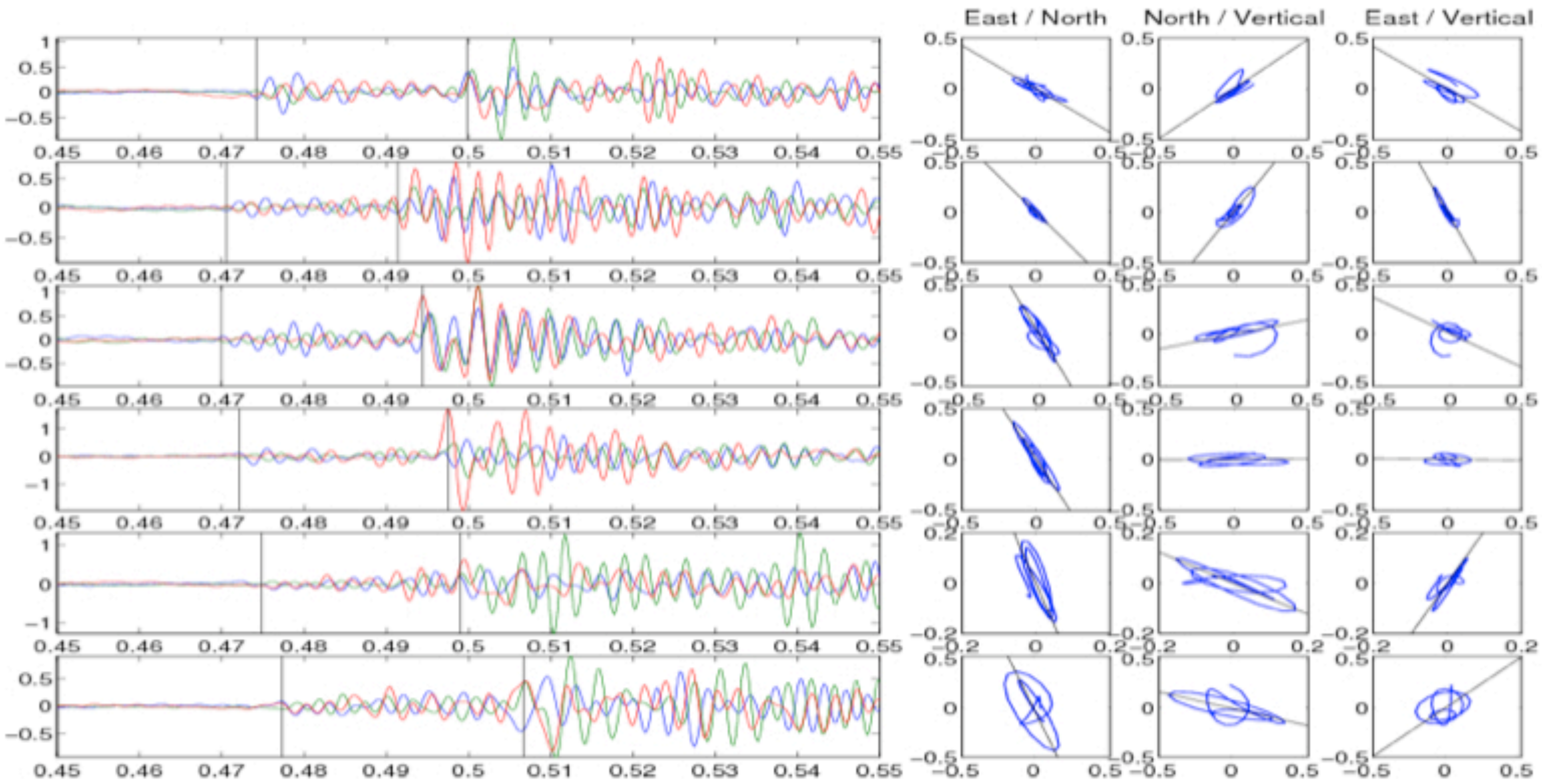




Earthquake Location

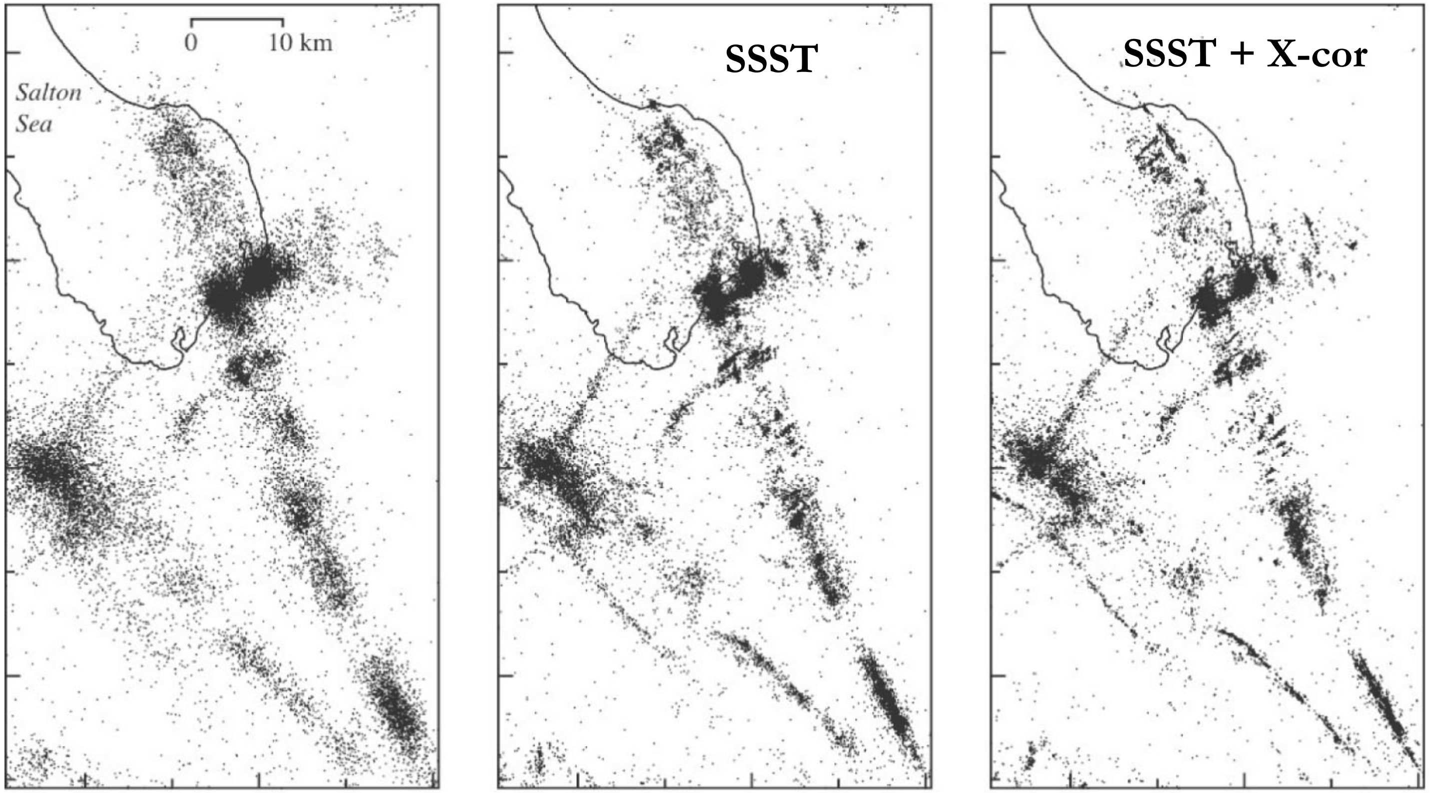
- Travel times and particle motion (azimuth and dip).





Relative event location

- Often use a ‘master’ event.
- Double difference locations (Waldhauser ad Ellsworth, 2000)
- Source-specific station term method (Richards-Dinger and Shearer, 2000)



Li et al., 2008

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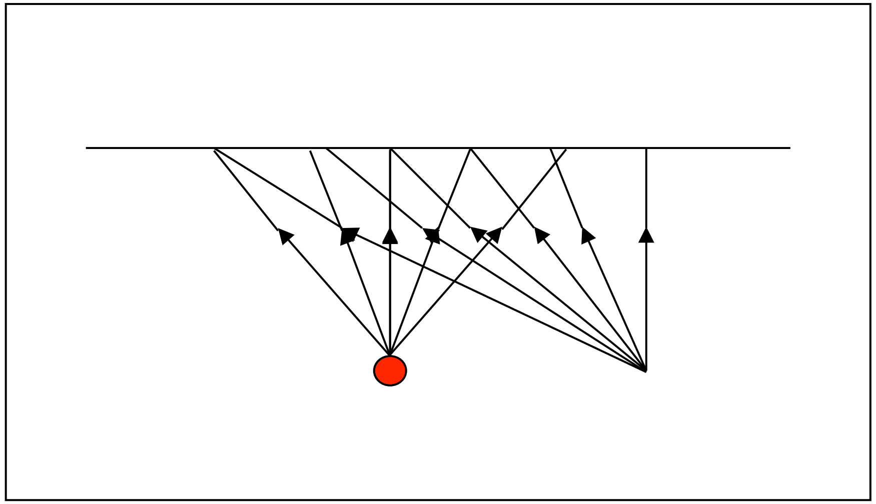
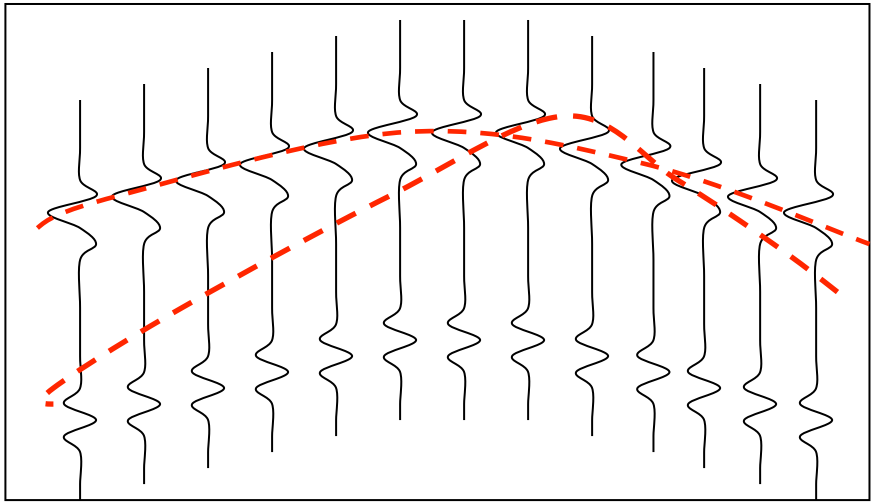
Using migration to image events

The basic idea

1. Make travel time tables for every sensor.
2. Pick a point in the subsurface.
3. Select all the data which could have come from it.
4. Add it up to get a stack amplitude.





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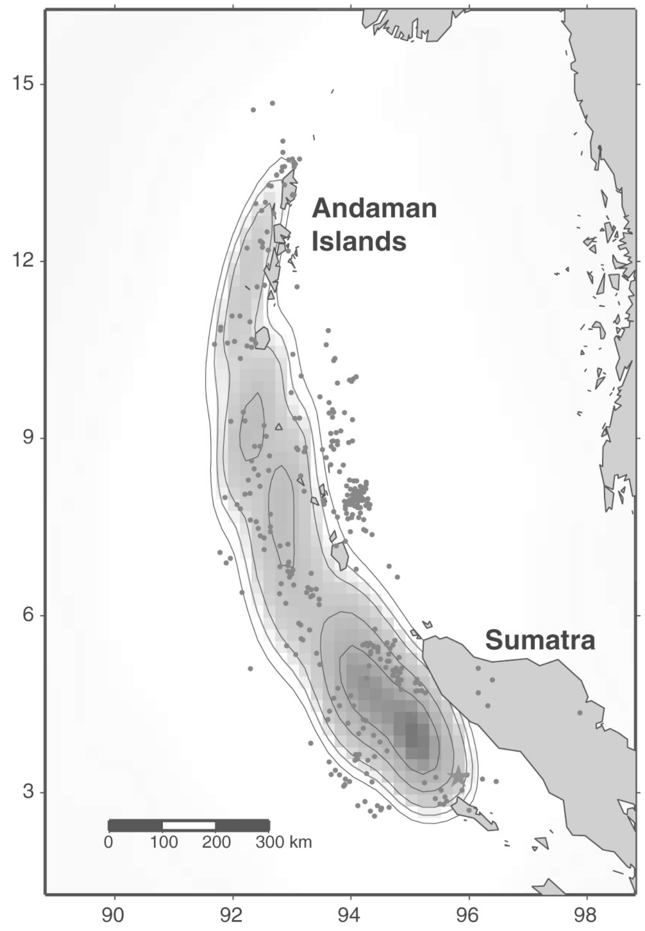
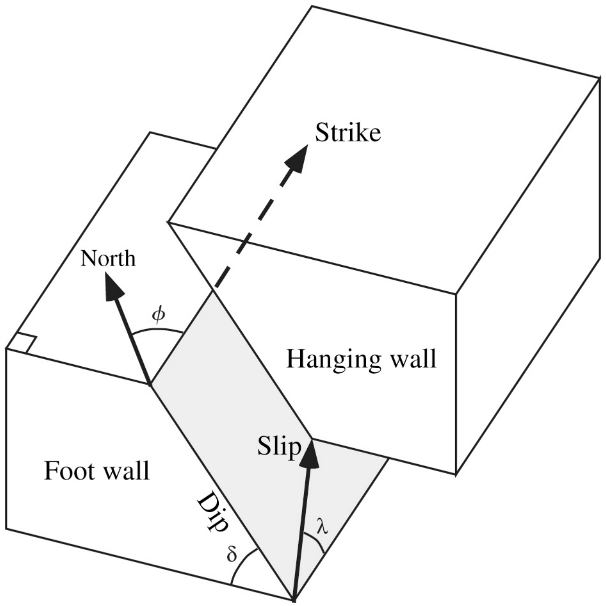
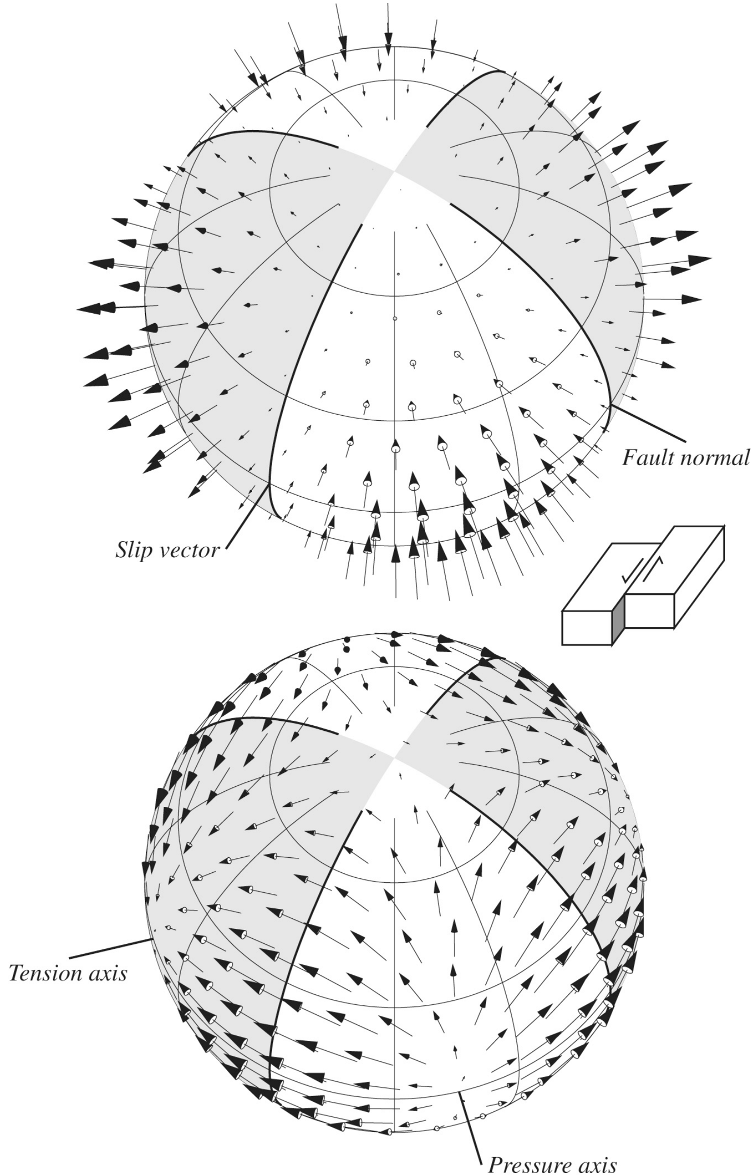
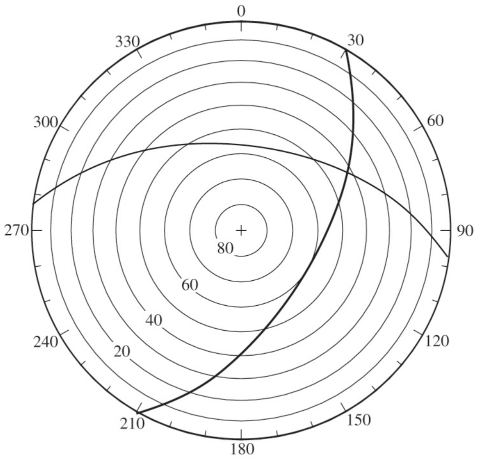
Earthquake dynamics - migration

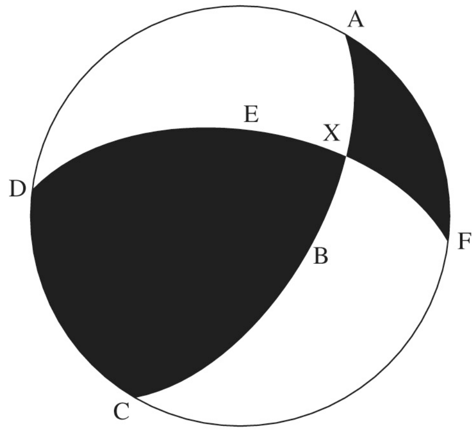


Source mechanisms

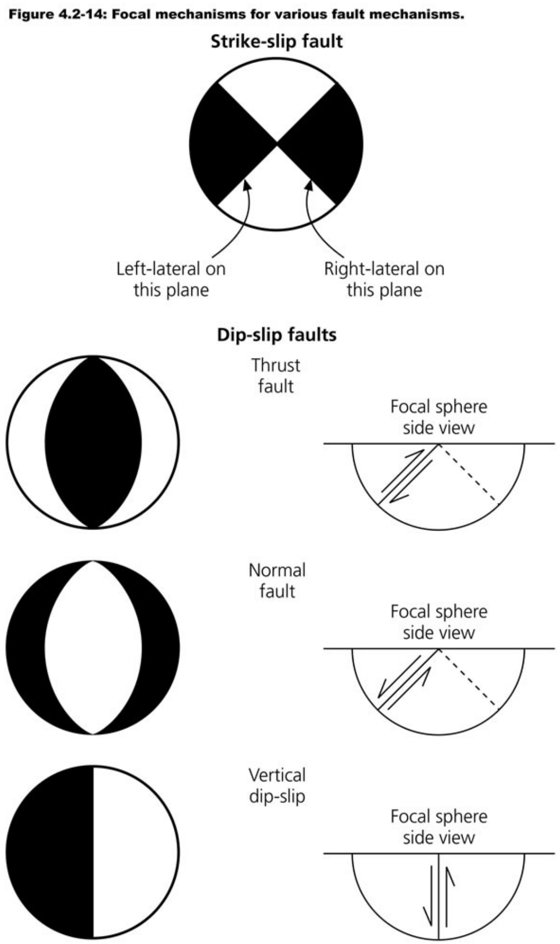








Basic earthquake types



Strike-slip

Thrust/reverse

Dip-slip/normal

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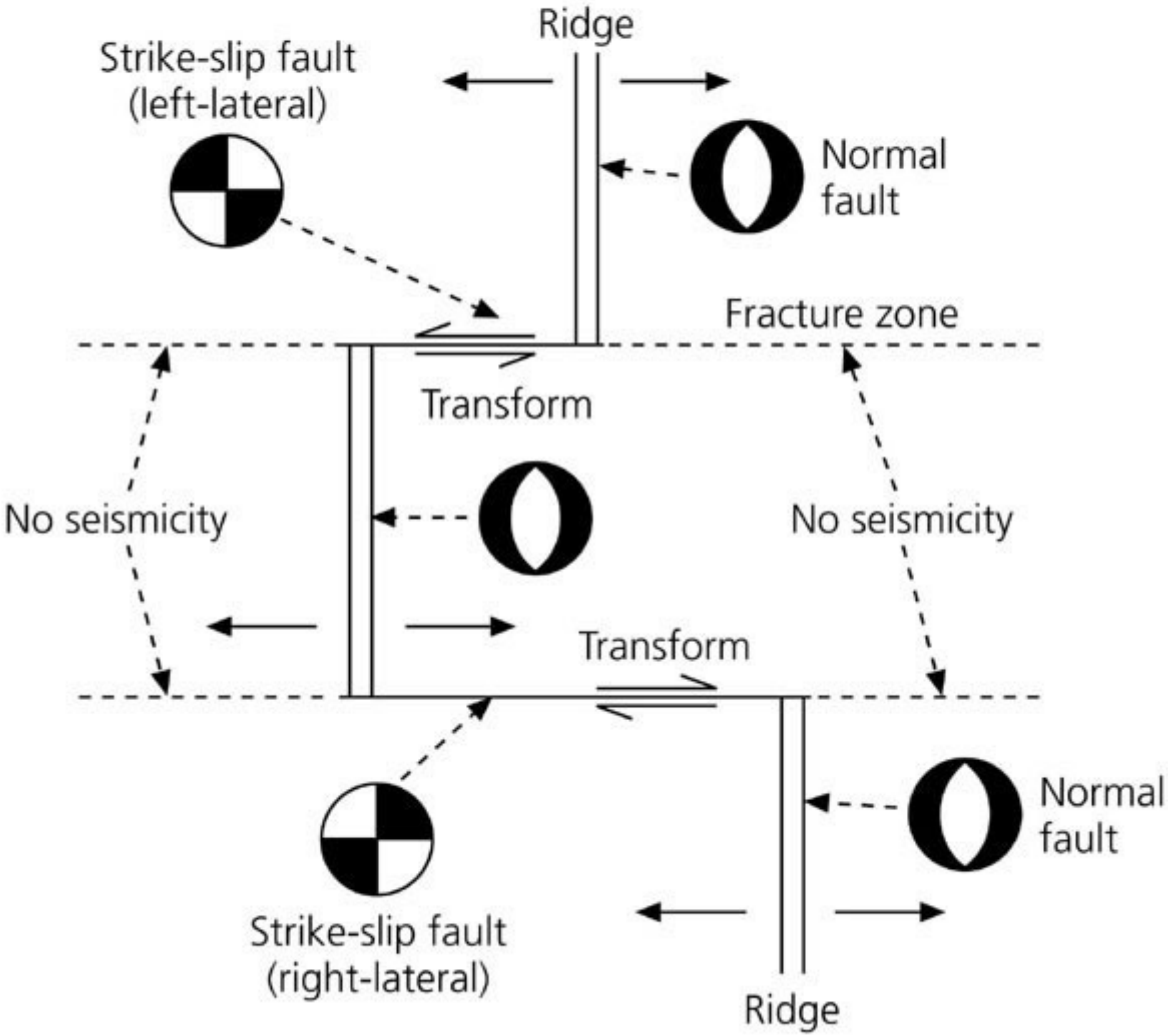
Figure 5.3-1: Tectonic settings of earthquakes along an oceanic spreading center.



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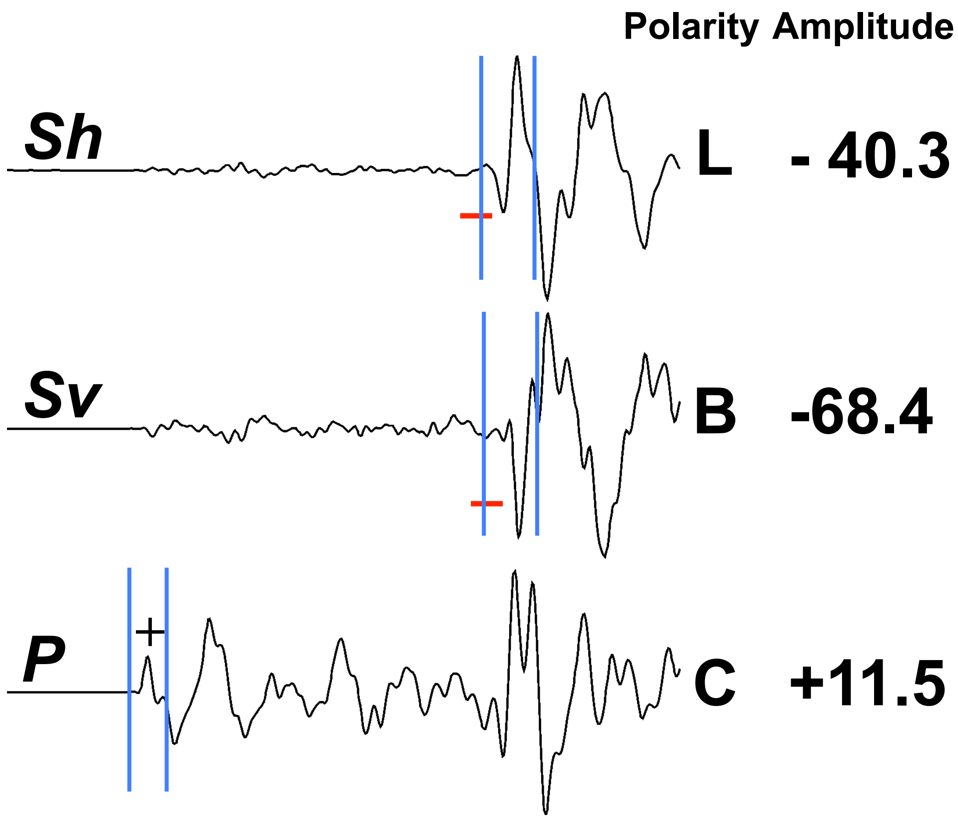
FOCMEC (Snoke, 1984)

Assumes: double-couple (pure shear) source

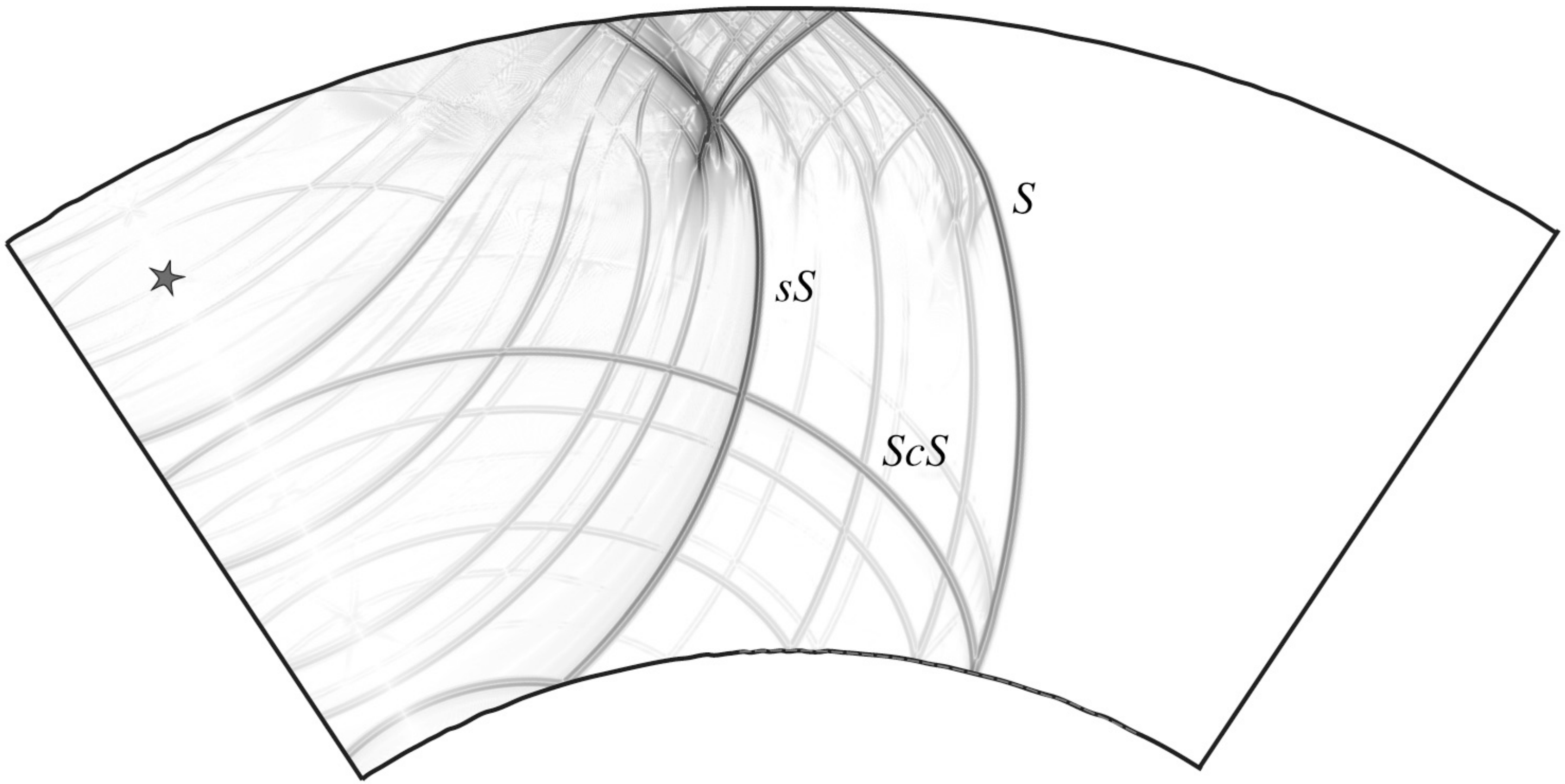
Method: Grid search

Uses: - (P,SV,SH) polarities and ratios
- ray (azimuth, take off angle)

Focal mechanism



Imaging the Earth's Interior



SH-wavefronts after 10mins from a source at a depth of 500km

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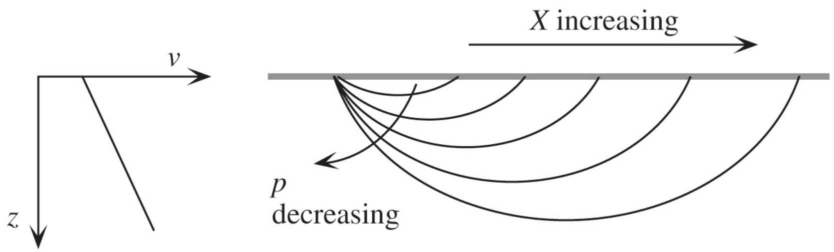
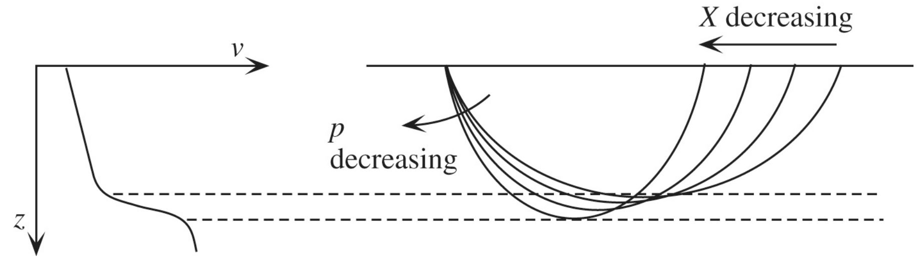
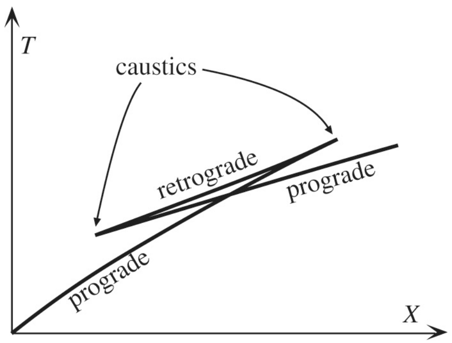
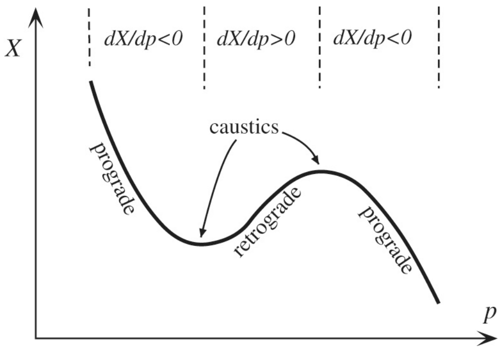
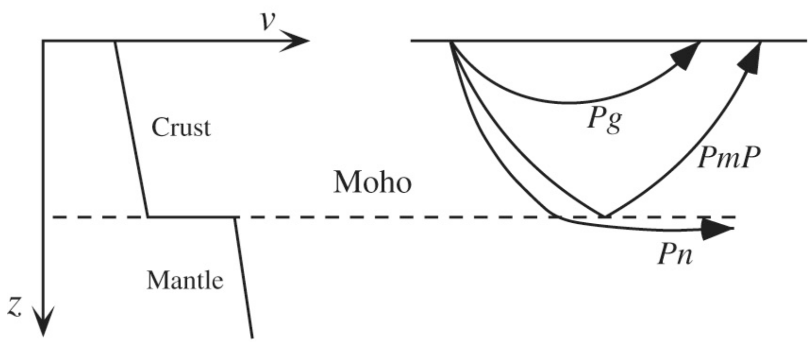
Rays, traveltimes and slowness

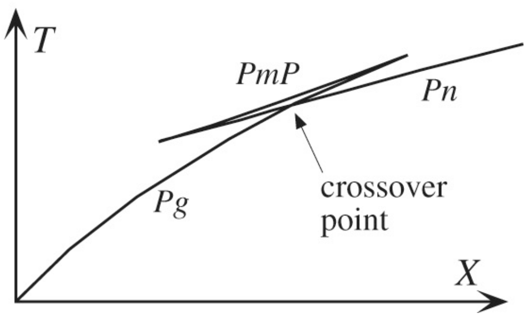












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The anatomy of a seismogram: body waves, surface waves, modes

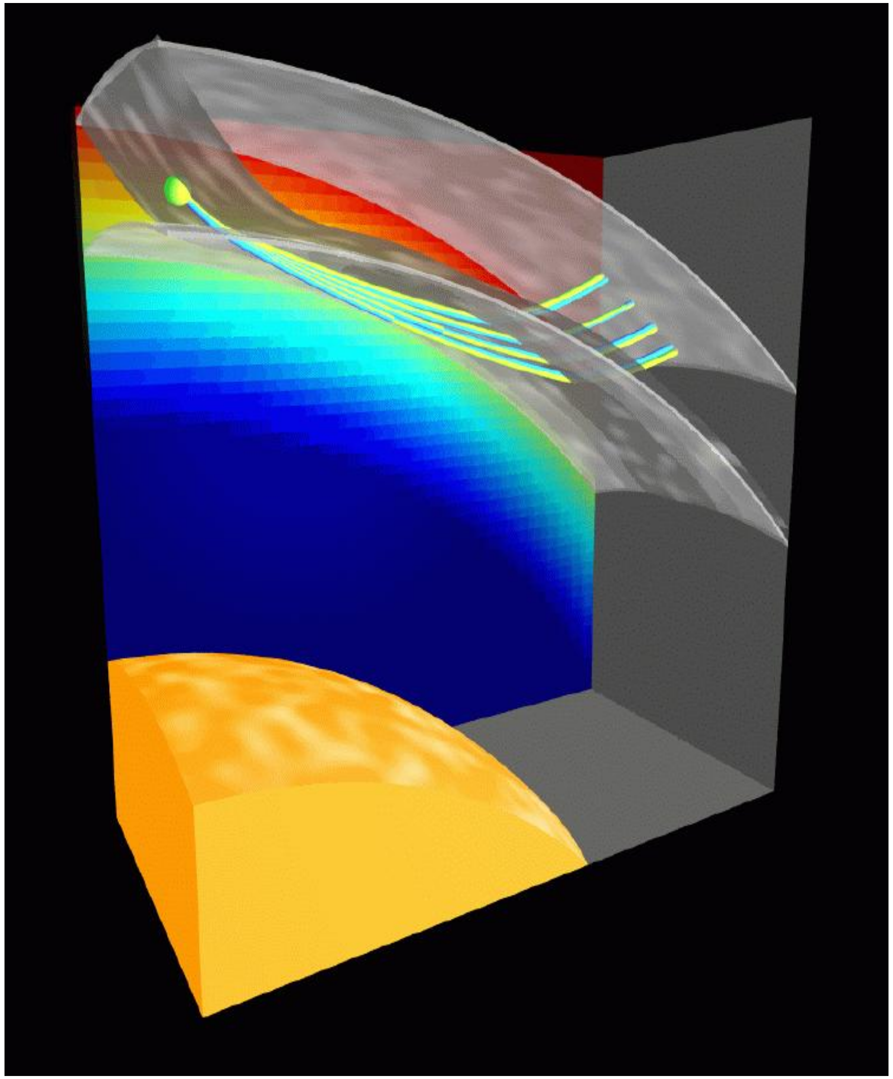
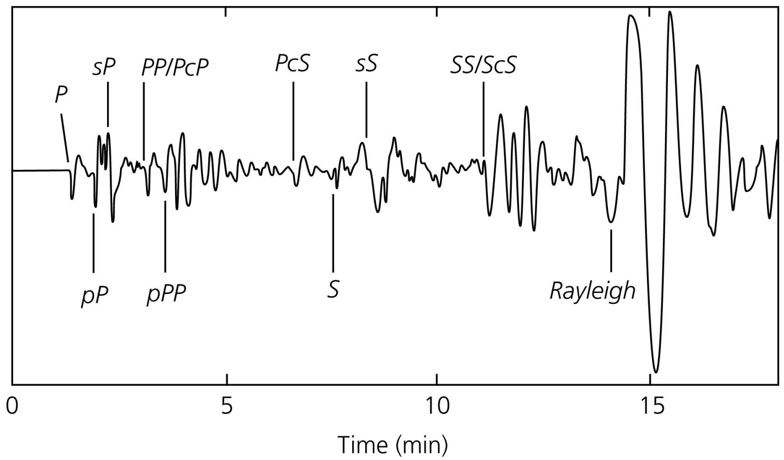
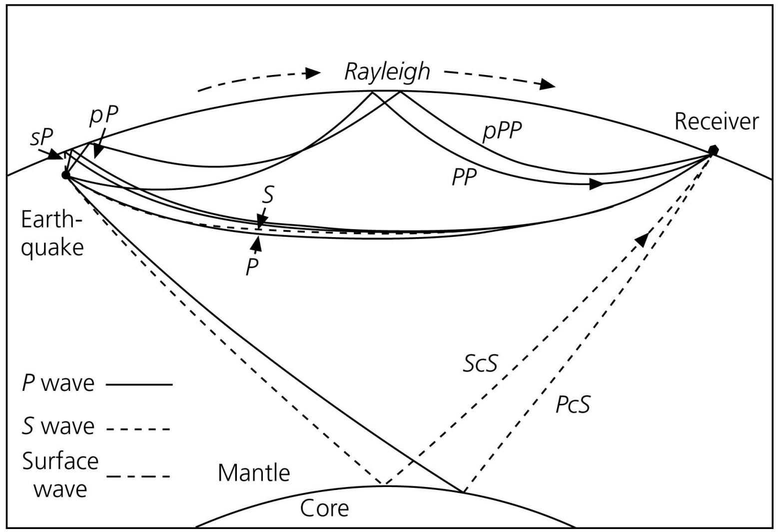


Figure 3.5-2: Selection of body phases and their ray paths.





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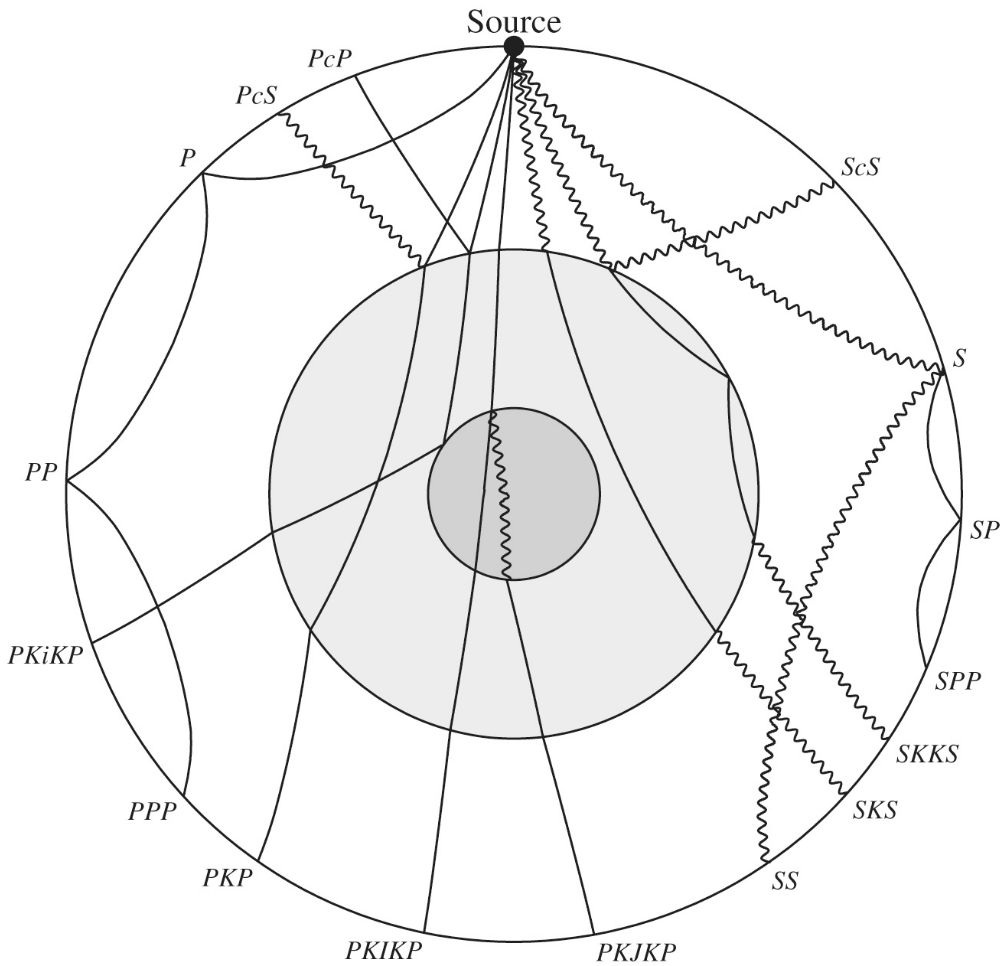
Whole Earth Seismic Phases



- P - P-wave in the mantle
- K - P-wave in the outer core
- I - P-wave in the inner core
- S - S-wave in the mantle
- J - S-wave in the inner core
- c -reflection off the core-mantle boundary (CMB)
- i - reflection off the inner-core boundary (ICB)

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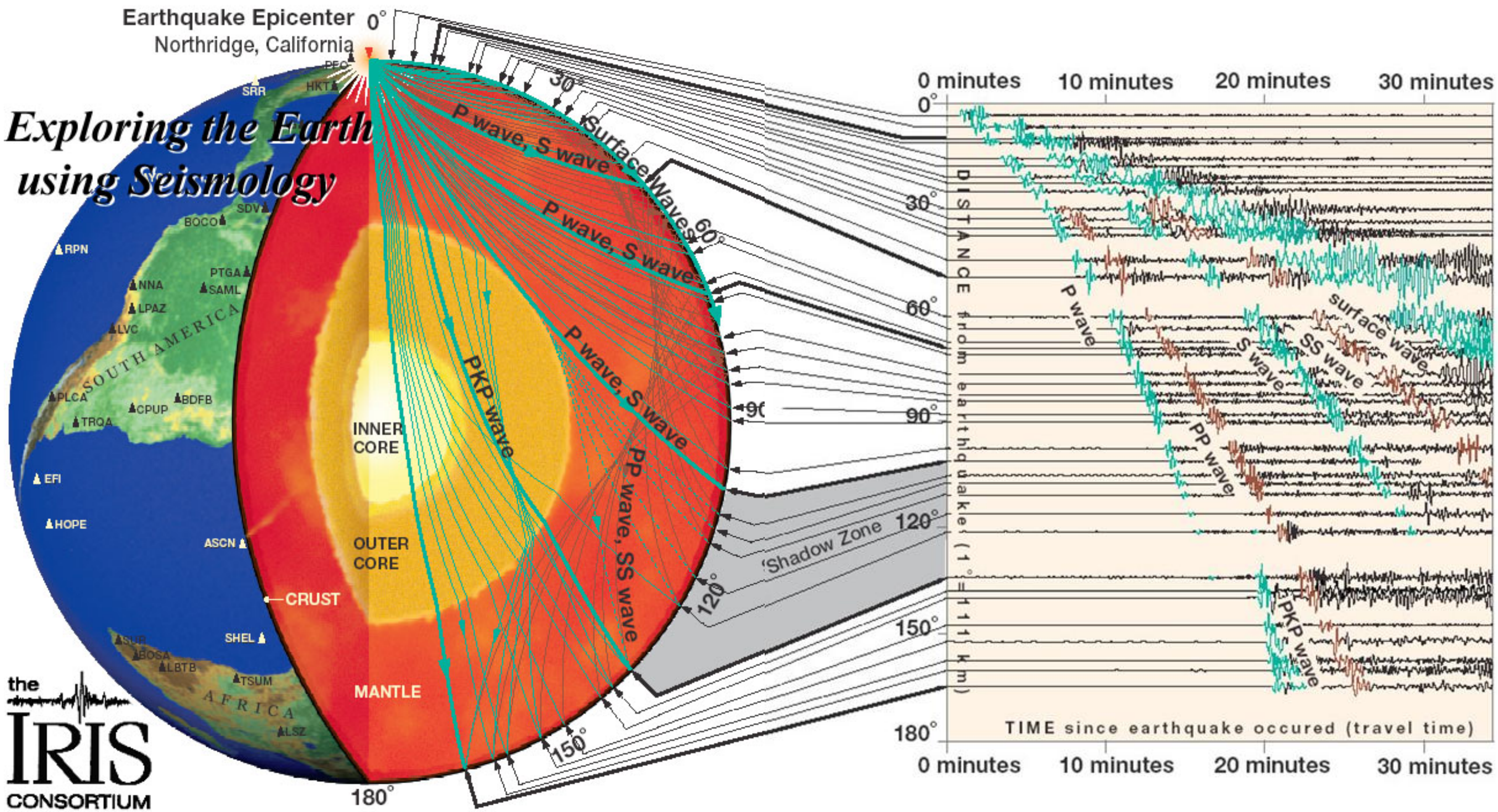
The anatomy of a seismogram



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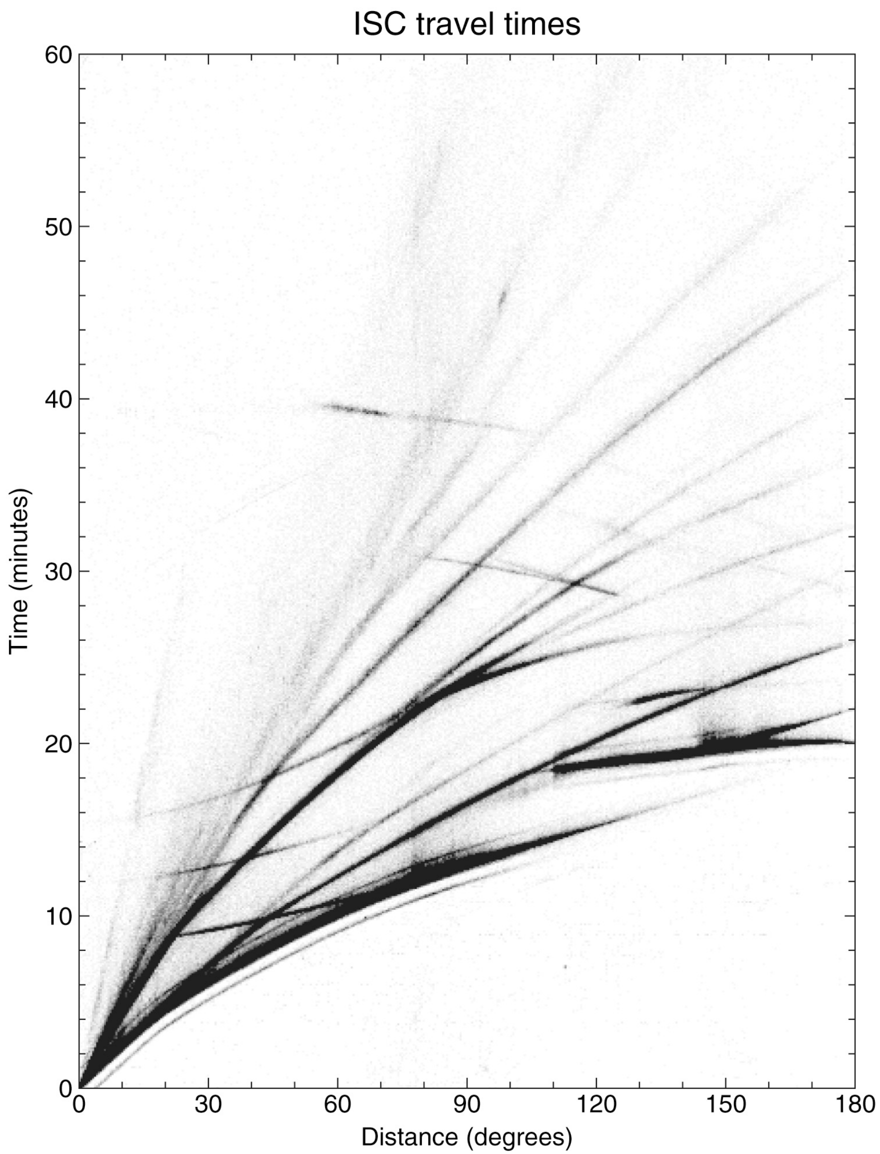
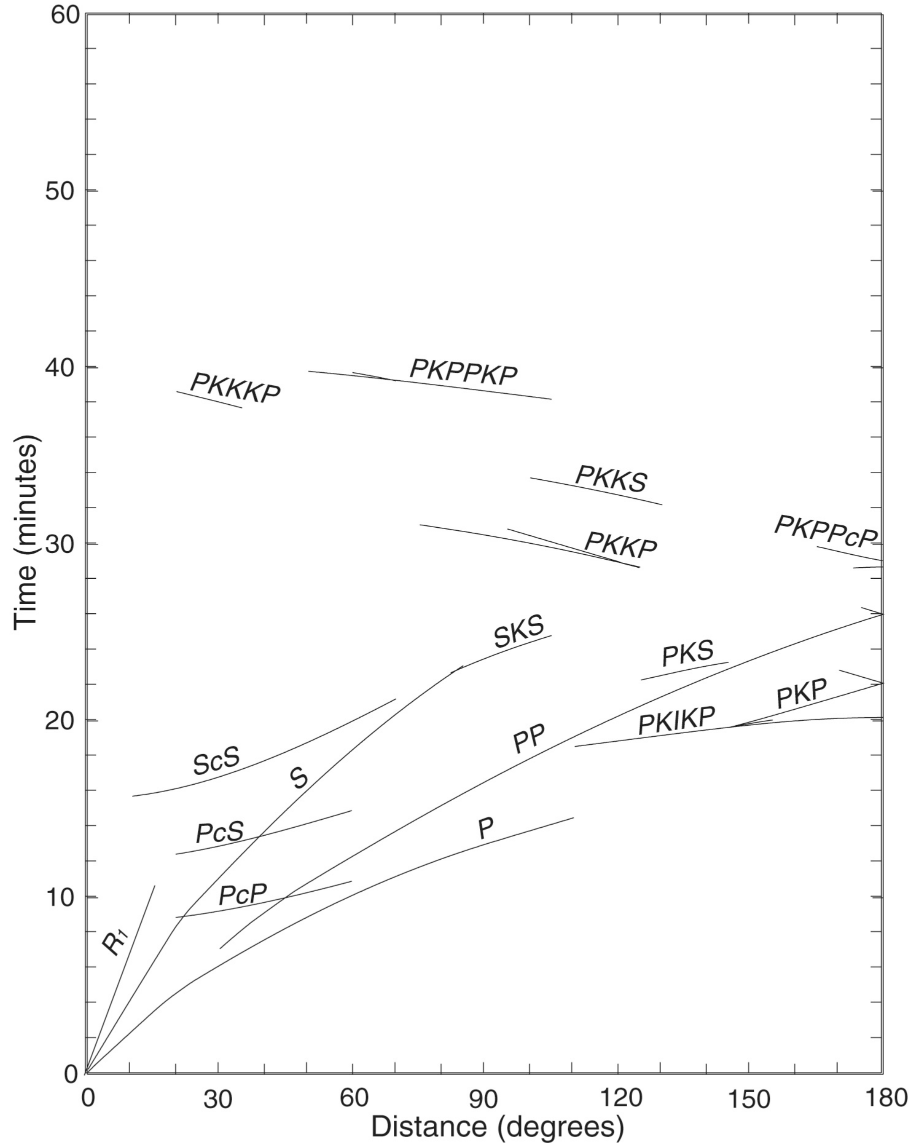
Global travel times





Surface waves

Figure 2.7-4: Six-hour stacked IDA record section.

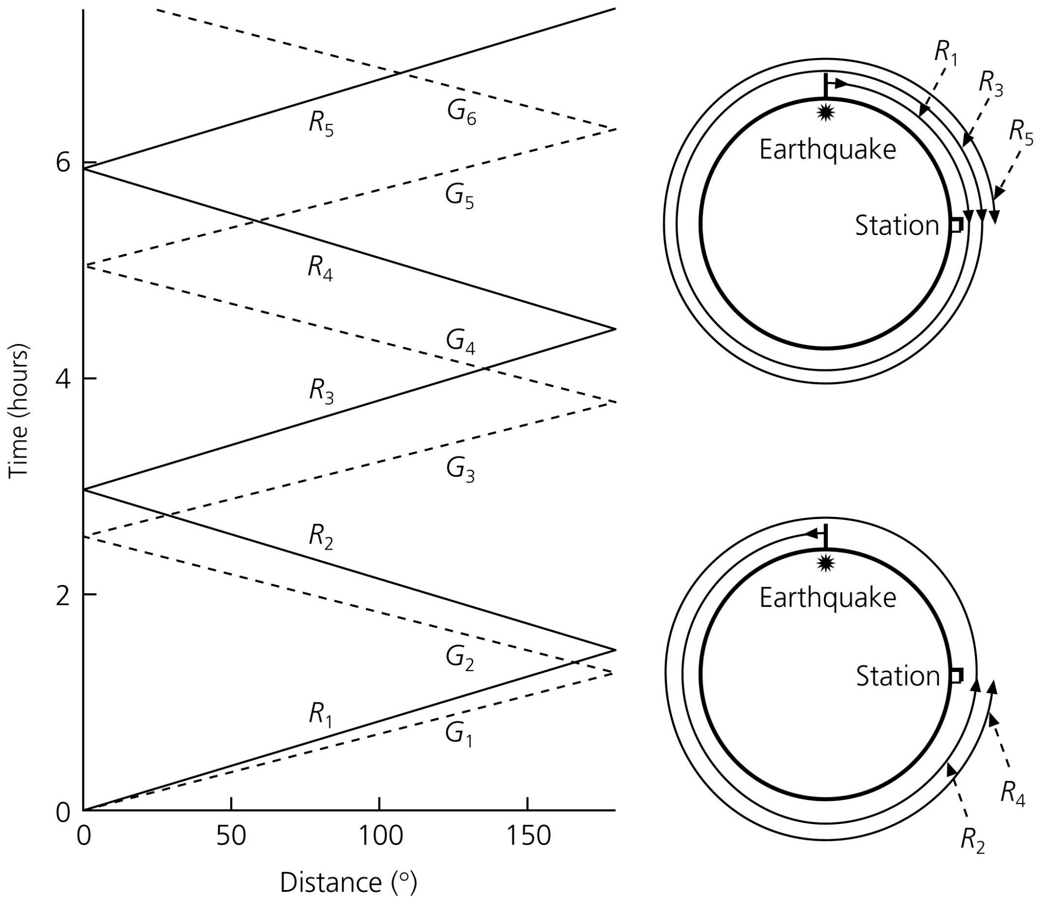
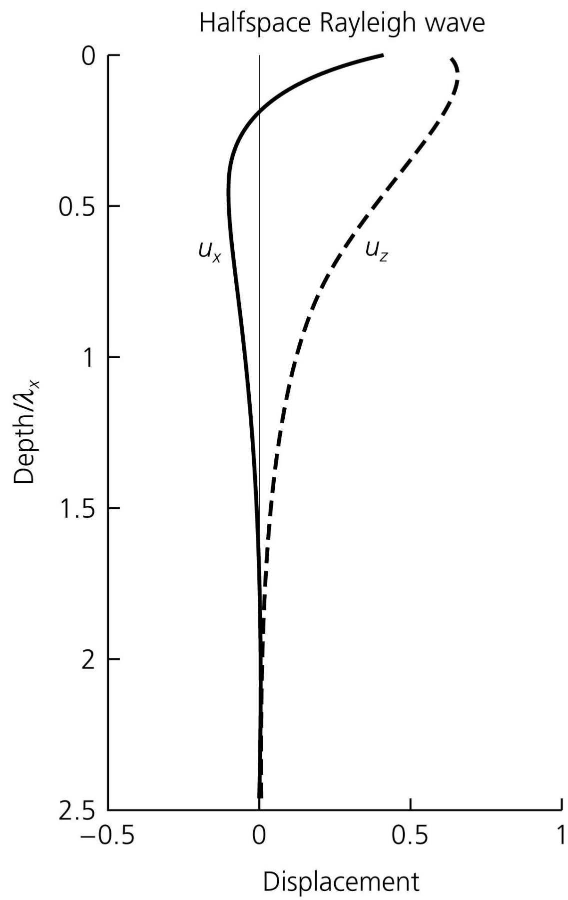


Figure 2.7-5: Rayleigh wave displacements as a function of depth.



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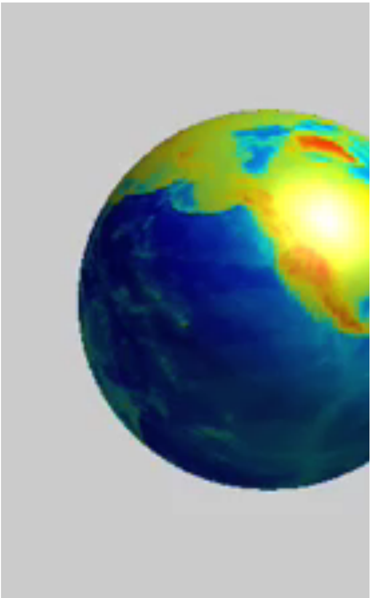
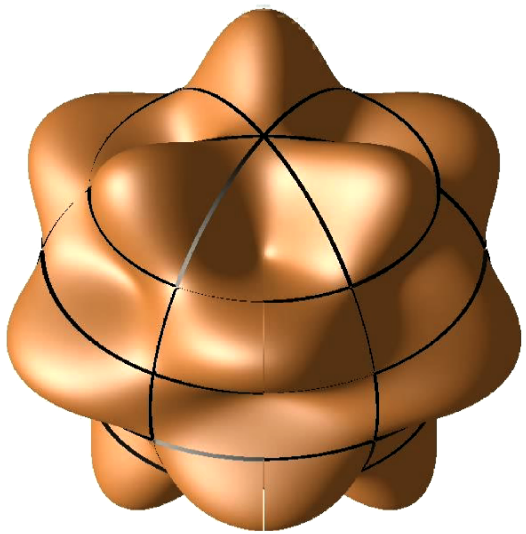
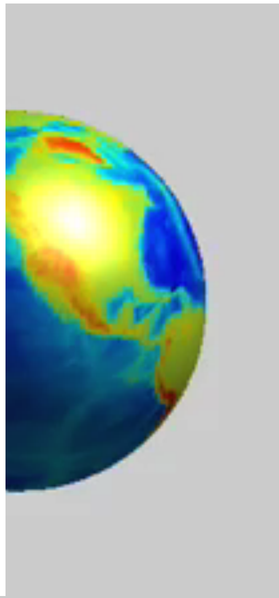
Normal modes







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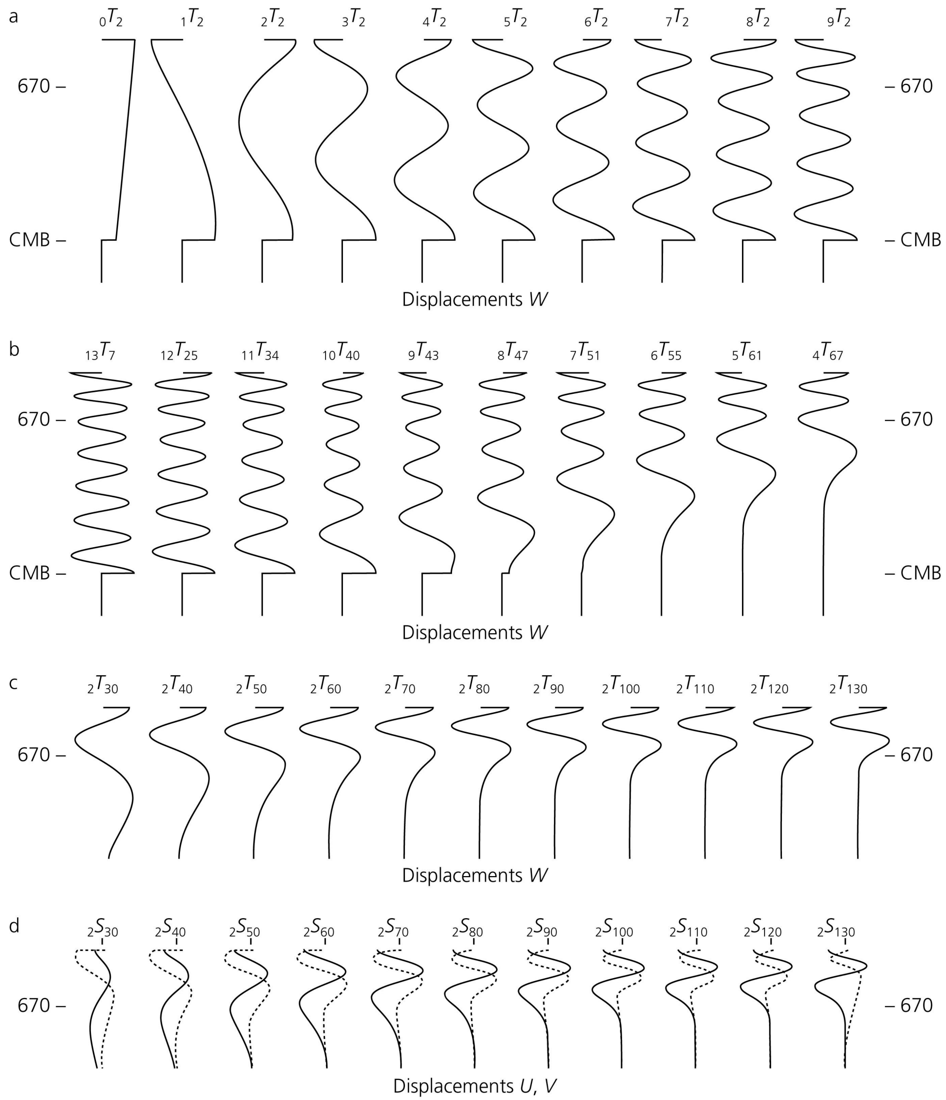
Normal modes

Figure 2.9-9: Radial eigenfunctions for various modes.



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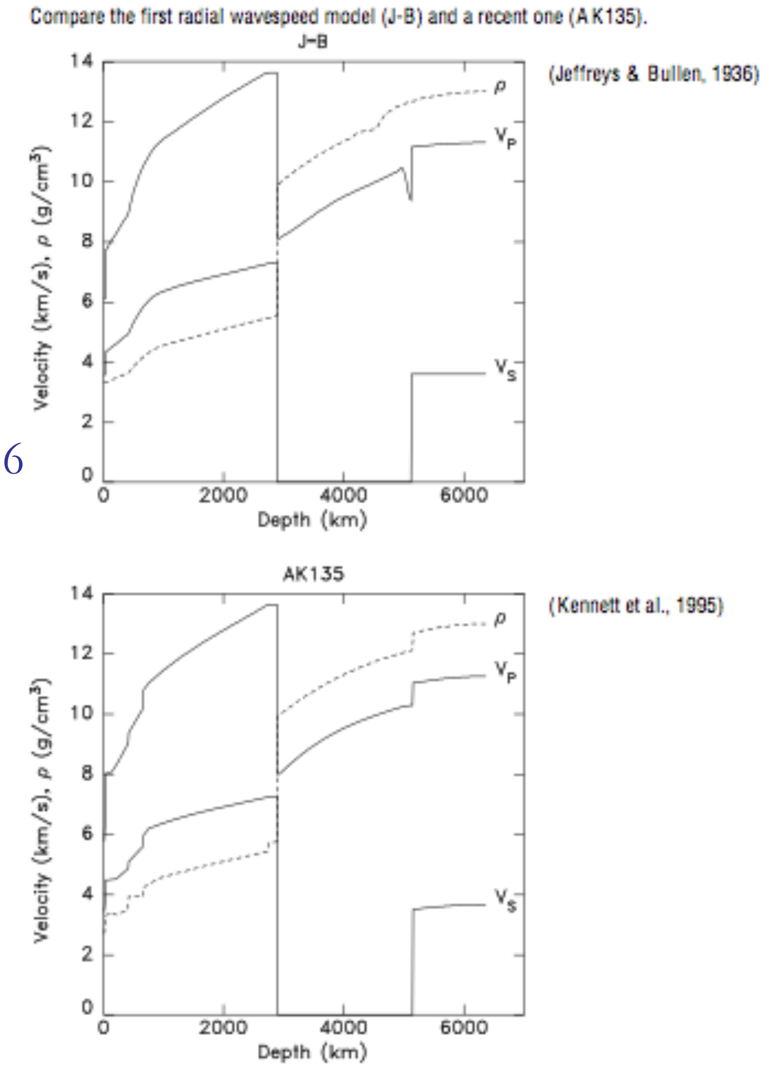
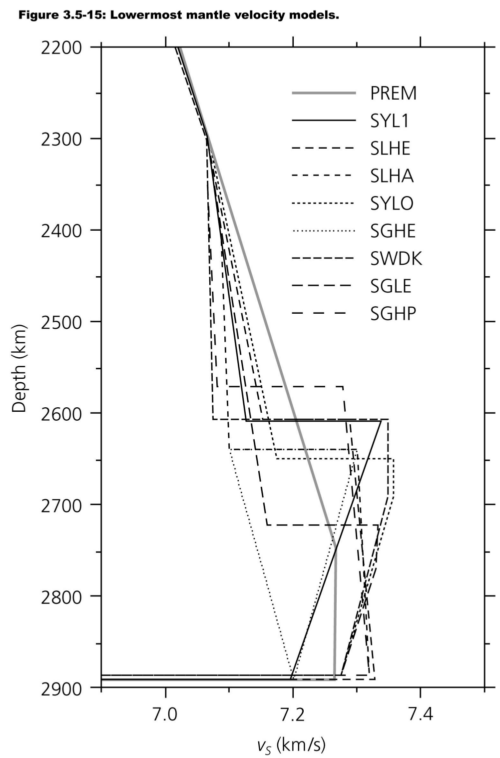
1D Earth Stucture



Jeffreys-Bullen 1936

AK135 1995



University of Bristol

The Crust - Mohorovicic discontinuity
(101th Anniversary)

Figure 3.2-1: Ray paths for a layer over a halfspace.

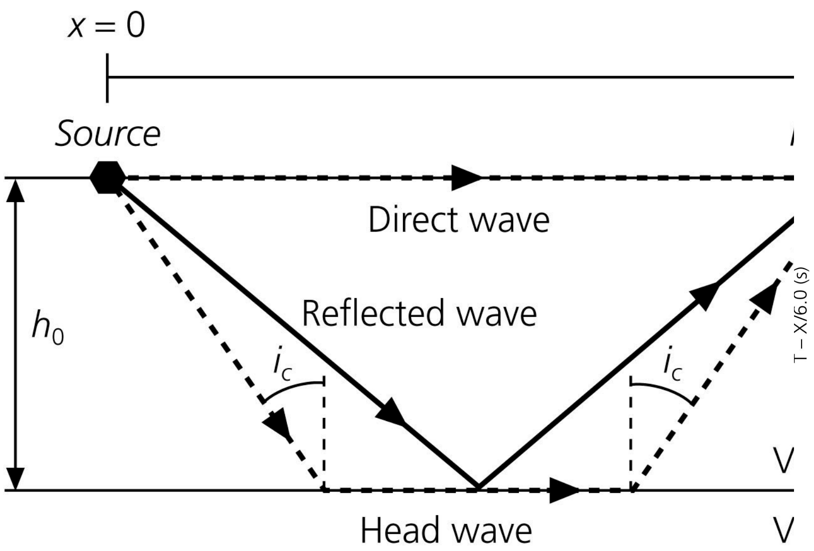
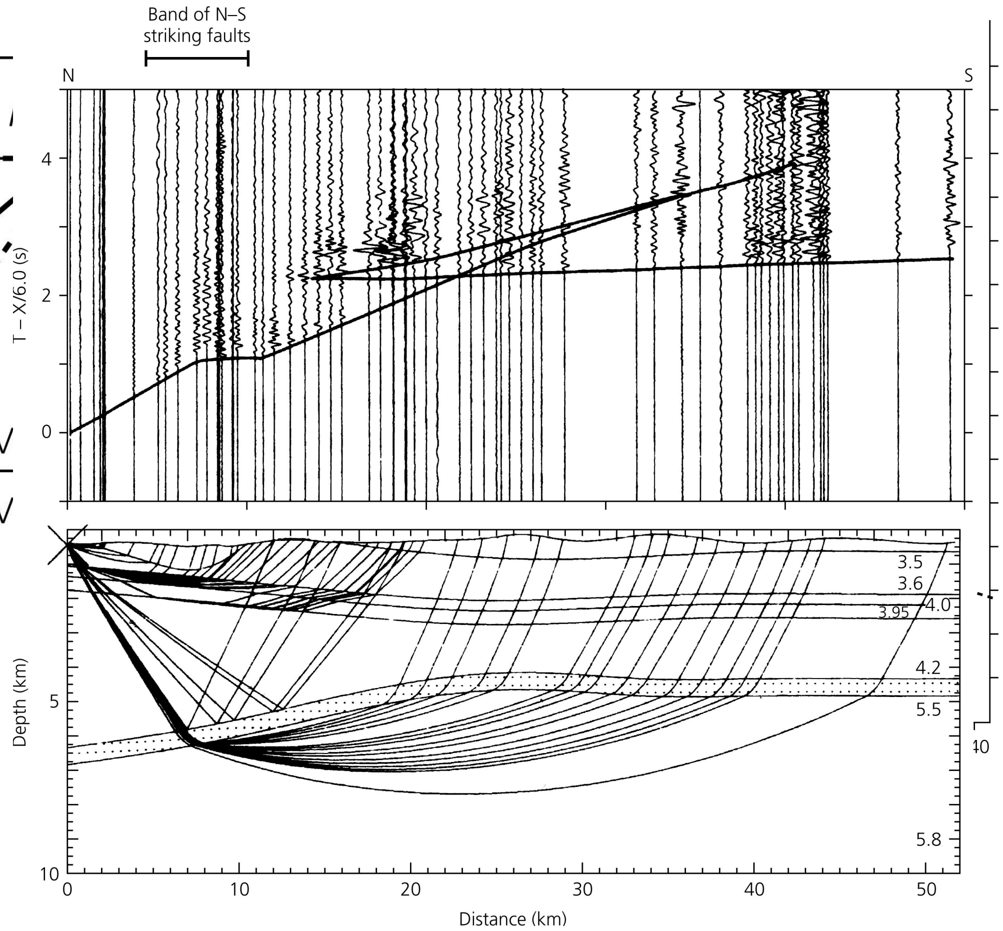
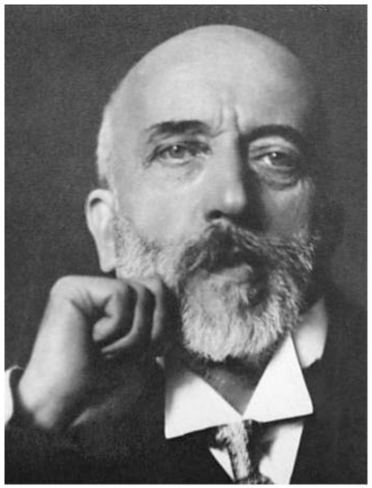


Figure 3.2-13: Seismic refraction survey with structural interpretation.





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Upper-mantle discontinuities

Figure 3.5-14: Upper mantle velocity models.

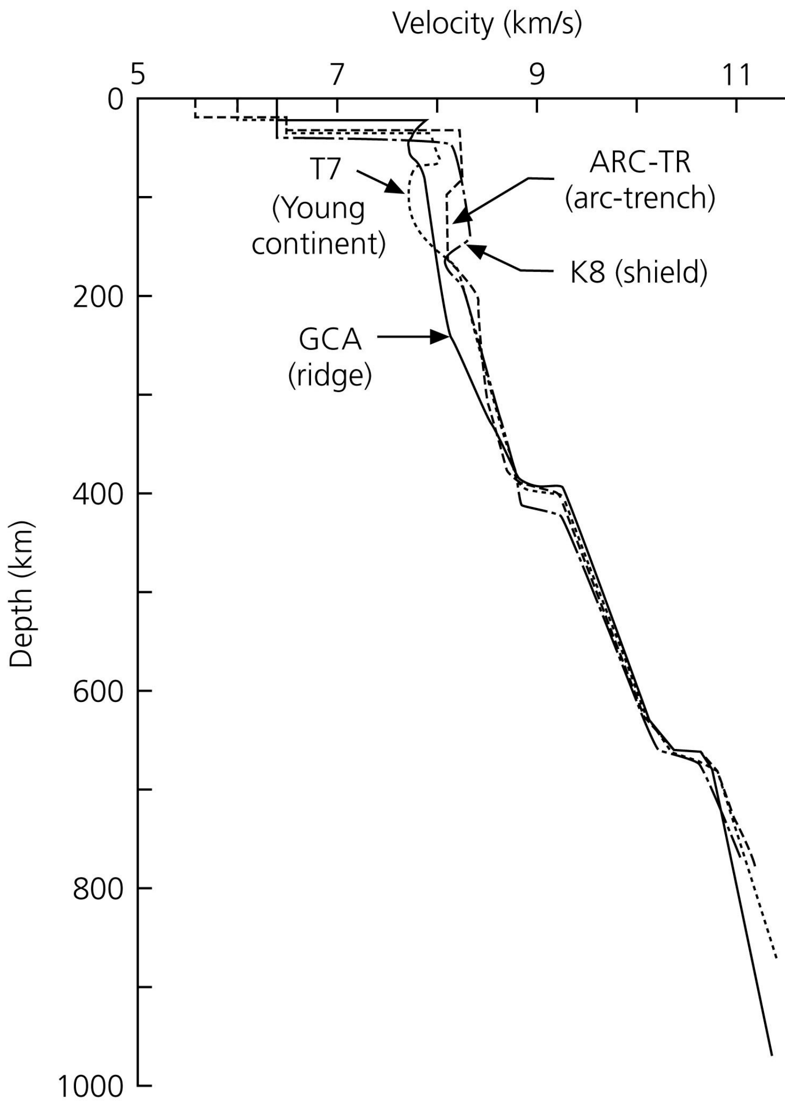
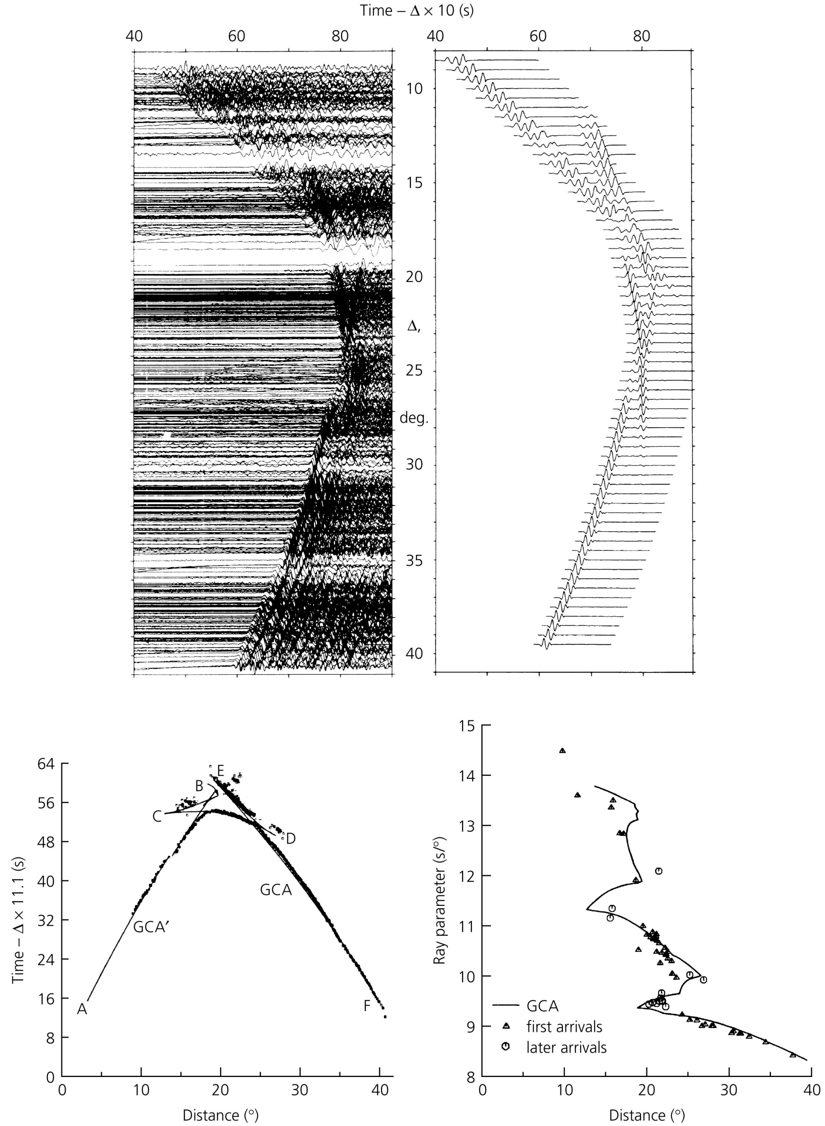
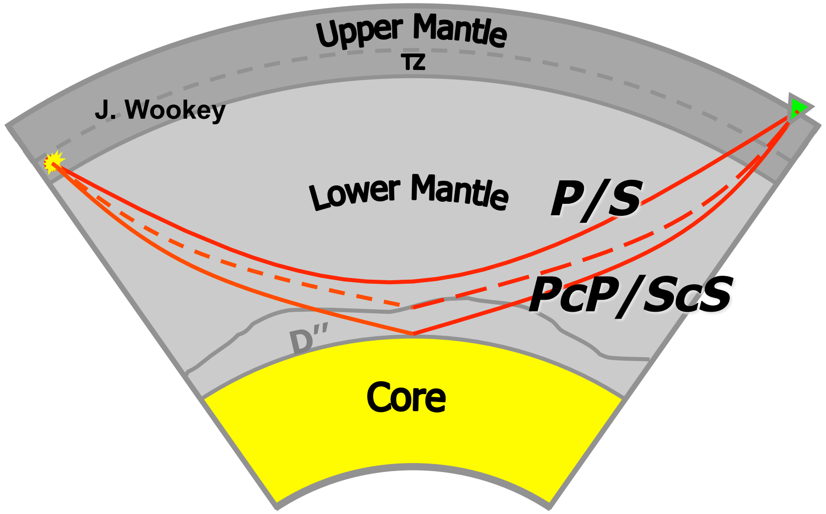


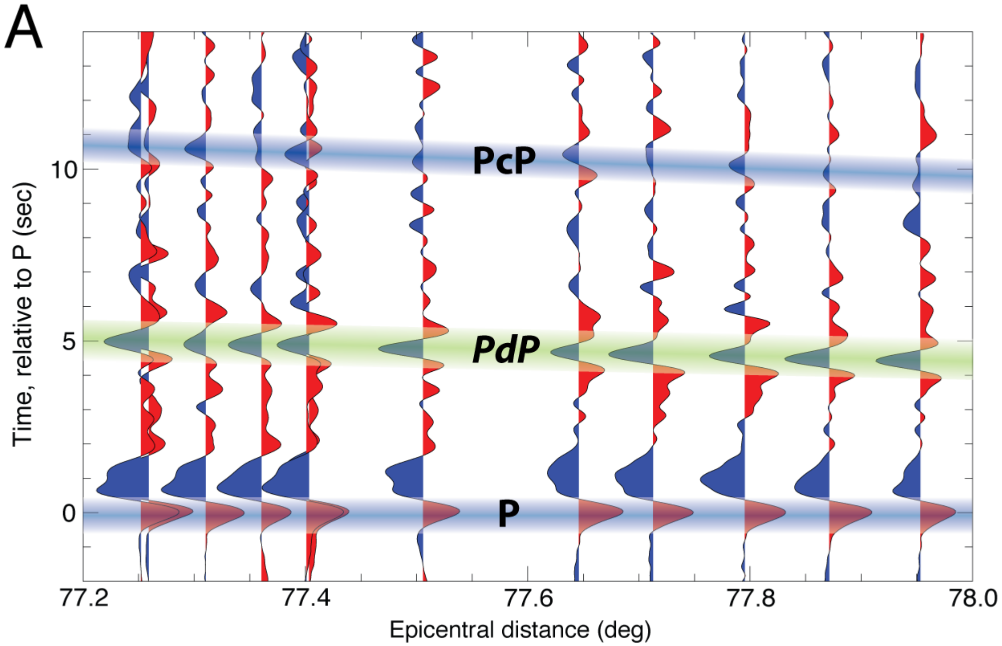
Figure 3.5-13: Seismic array study of upper mantle structure.

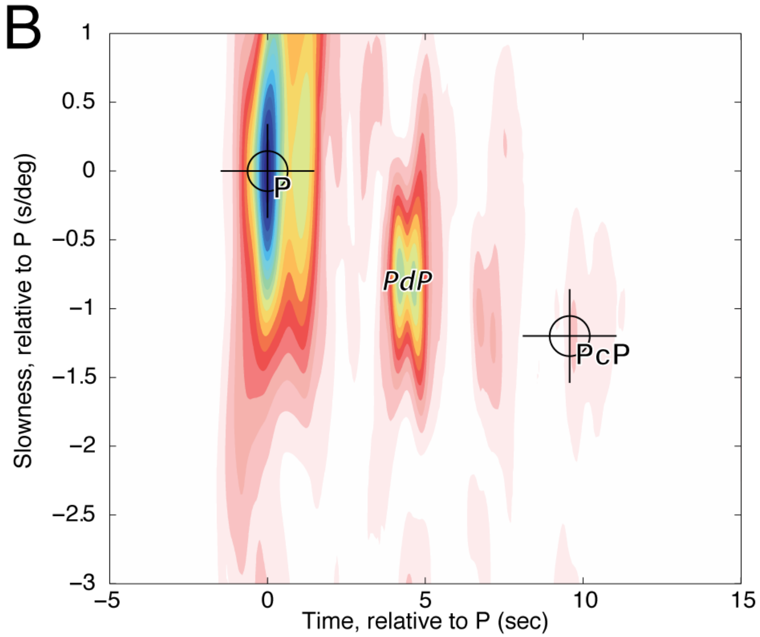


Lower Mantle Discontinuity (D'')

- In places D'' is observed as a sharp enough seismic discontinuity to both P and S waves to generate a reflected phase
- P-wave discontinuity *usually* weaker than S







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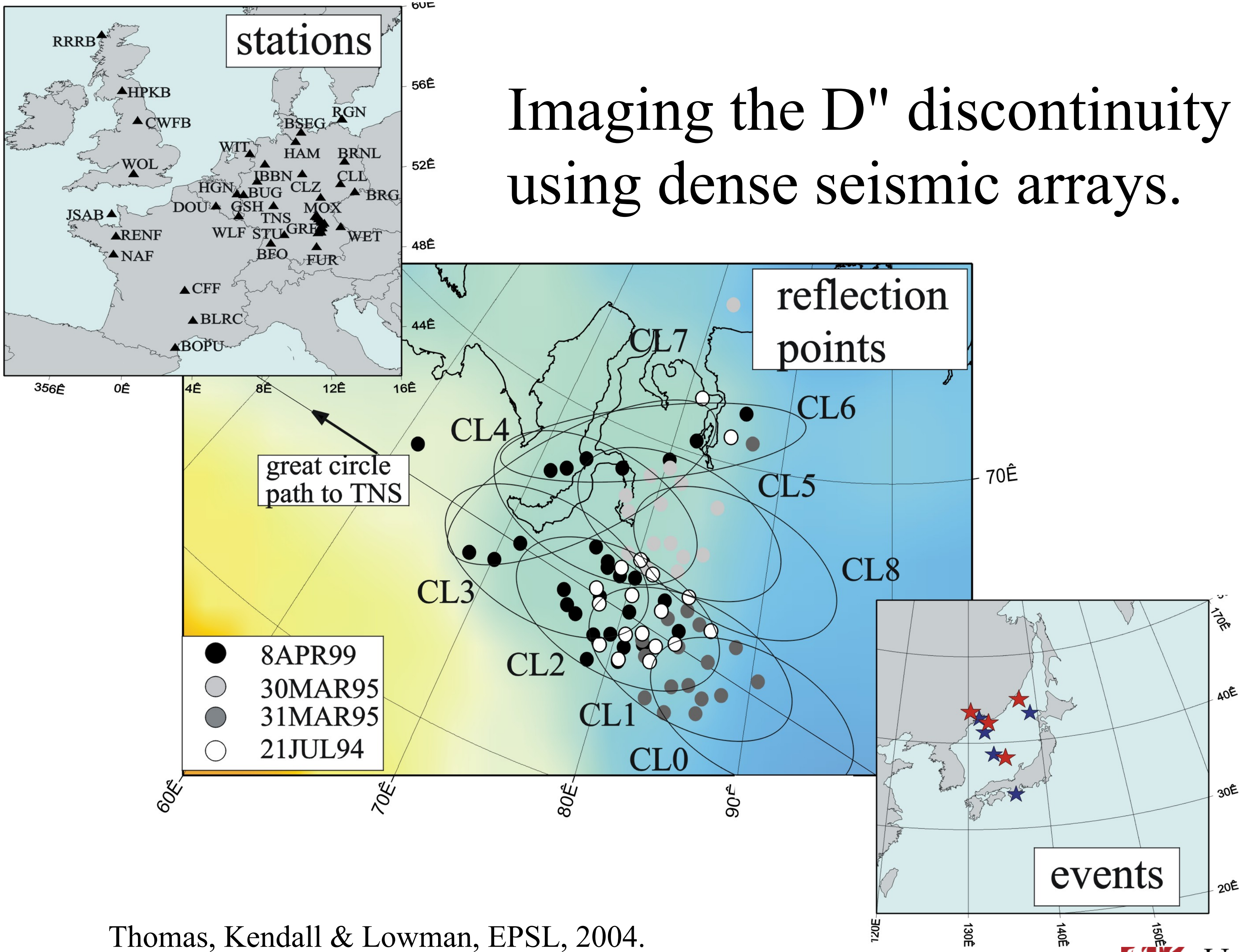
Imaging the D" discontinuity using dense seismic arrays.



Thomas, Kendall & Lowman, EPSL, 2004.

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Earth's Core

R. D. Oldham, Q. J. Geol. Soc., 1906.

'We know, with sufficient accuracy for most purposes, its size and shape: we know that its mean density is about 5.5 times that of water, the density must increase towards the centre, and that the temperature must be high, but beyond these facts little can be said to be known'

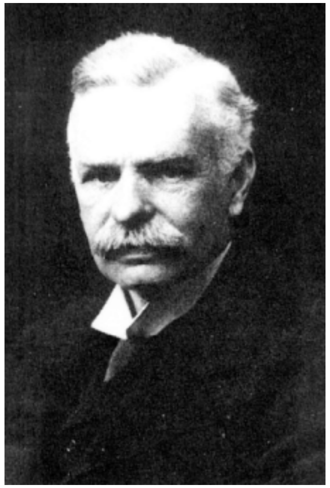
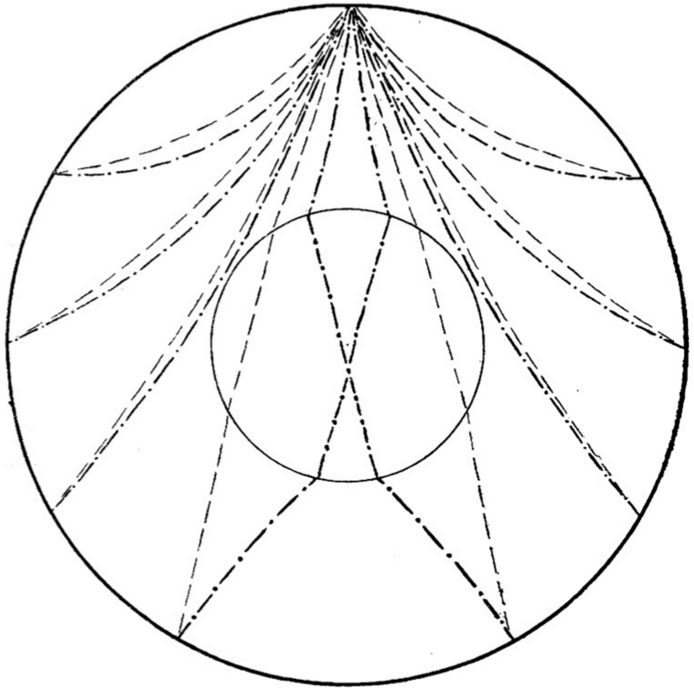


Fig. 3.



[The broken lines represent the first phase, the broken-and-dotted lines the second phase, and the continuous curve the third phase.]

- First teleseismic signal recorded in 1889!
- 14 earthquakes
- Limited network
- Deduced a molten core.

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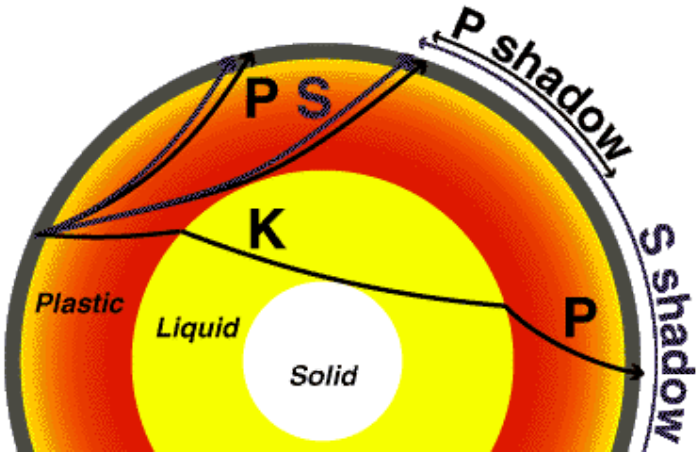
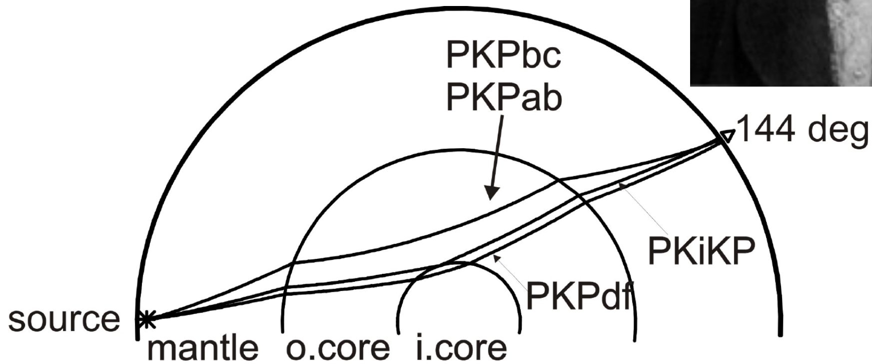
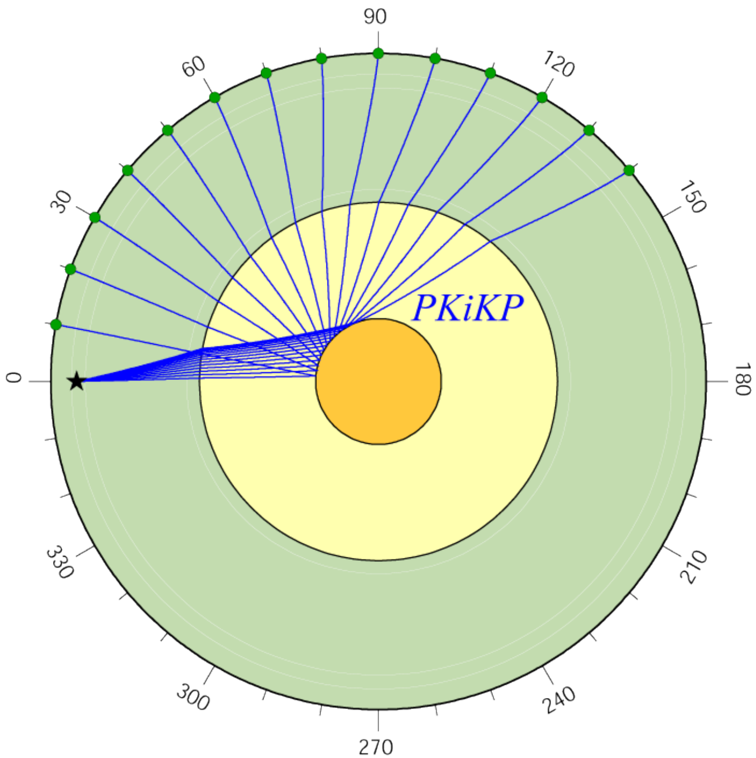
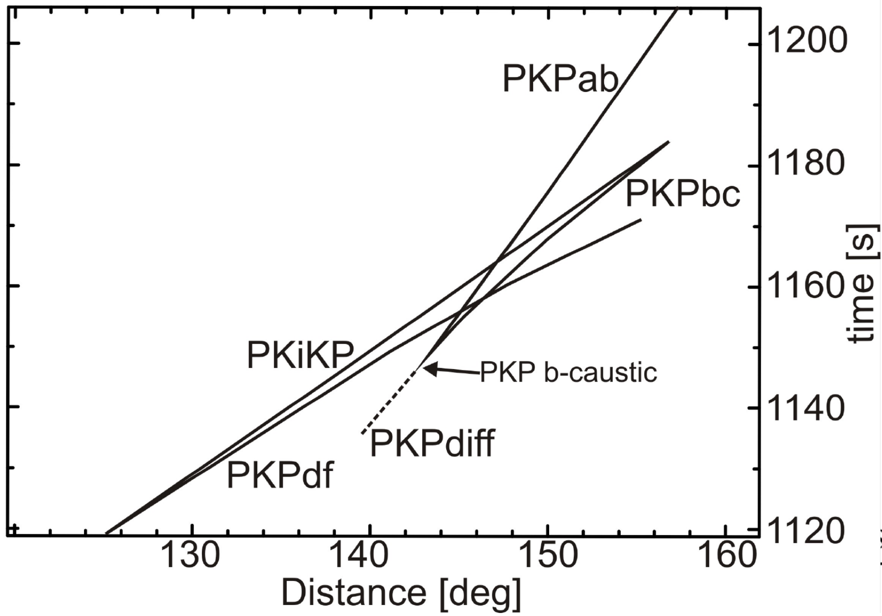
Earth's core









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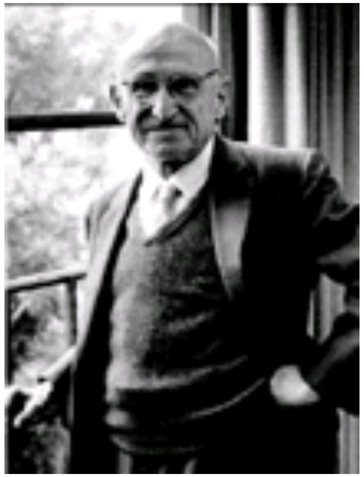
Earth's Core

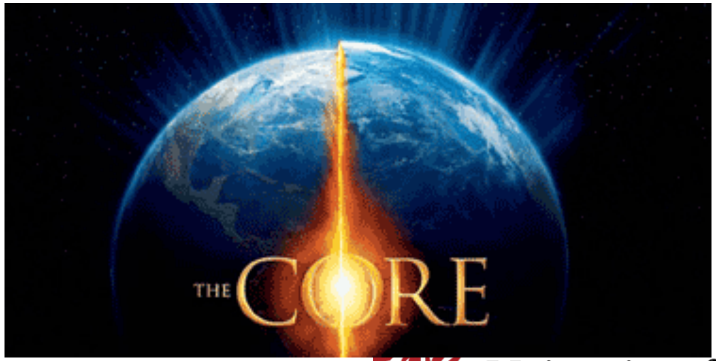


Outer core: 2891-5150km

- Liquid; nickel-iron; vigorously convecting.

Inner core: 5150-6371km.

- Solid; nickel-iron
- May be rotating differentially w.r.t. mantle.
- Light elements; O, S, Si, K, may float to the edge of the core (sediments).
- May be a mushy layer between inner core boundary.



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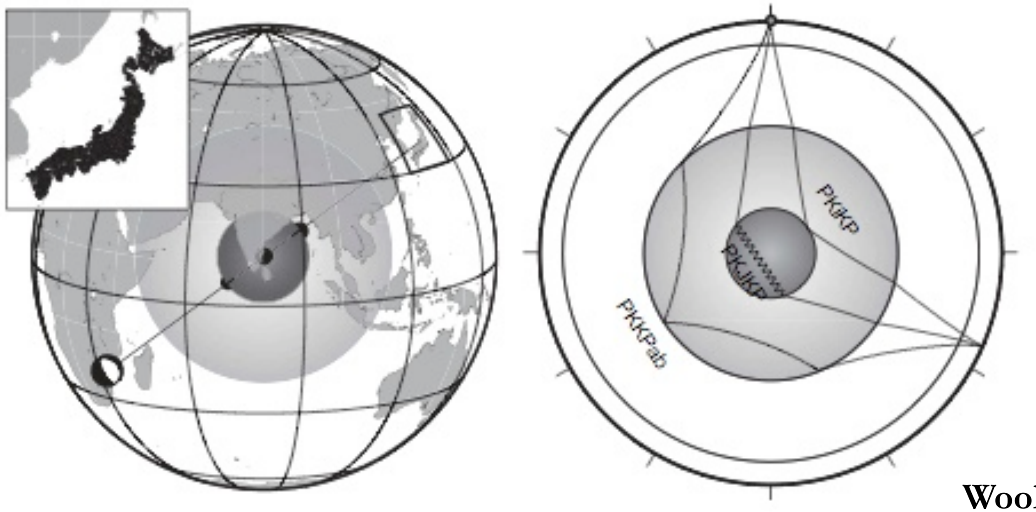
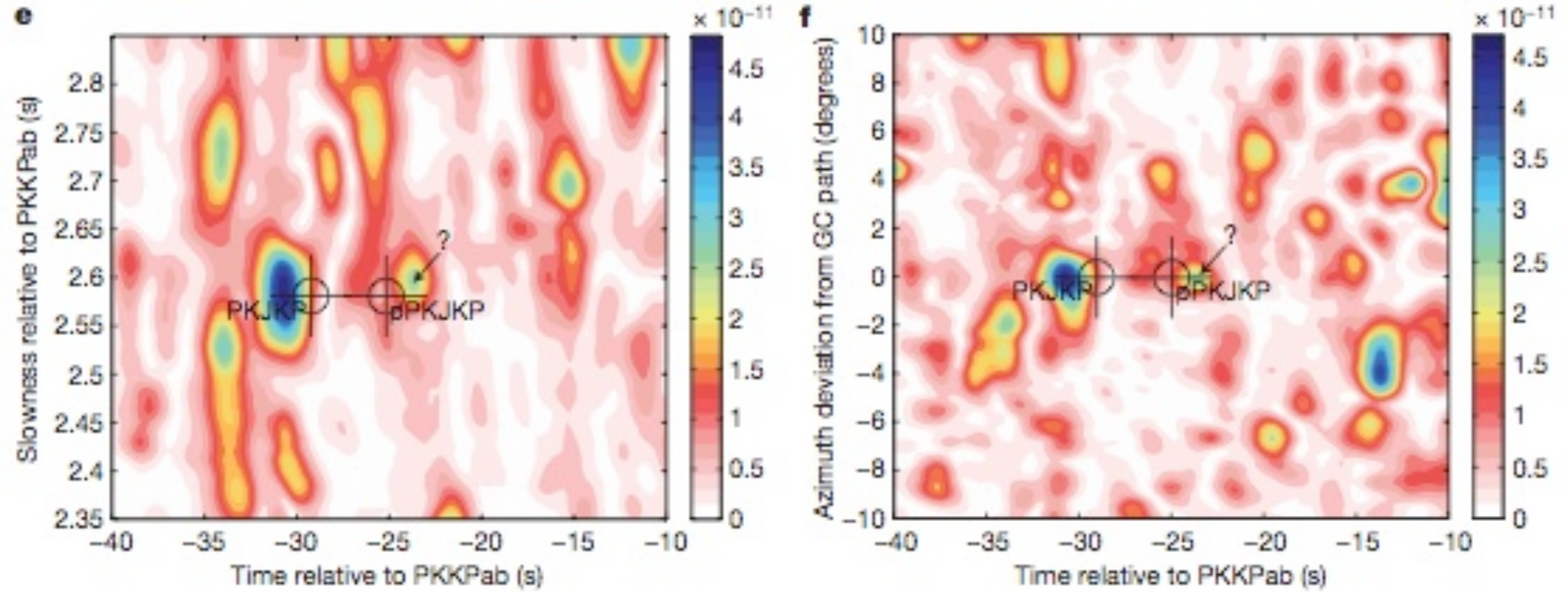
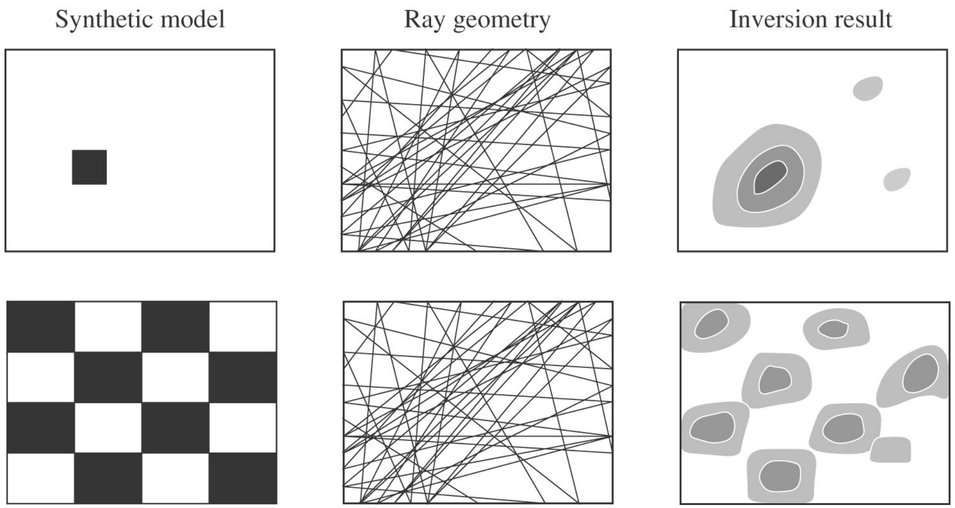
PKJKP

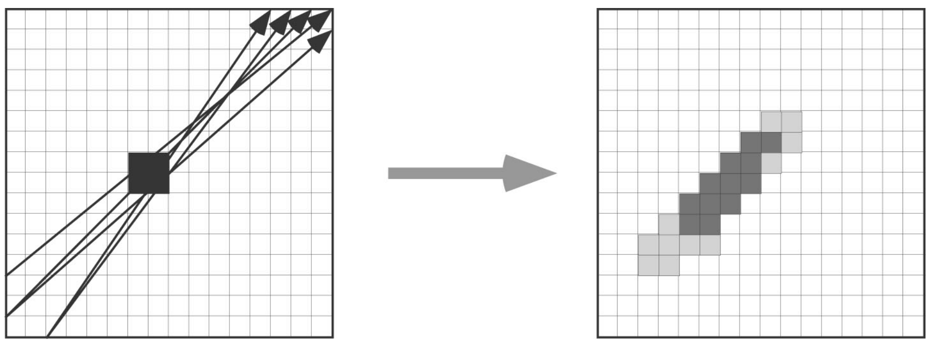


Wookey and Helffrich, 2009



Travel-time Tomography





- Pick travel times
- Relative (regional) versus absolute time (global)
- Model parameterisation
- Linear versus non-linear inversions
- Isotropic versus anisotropic Earth

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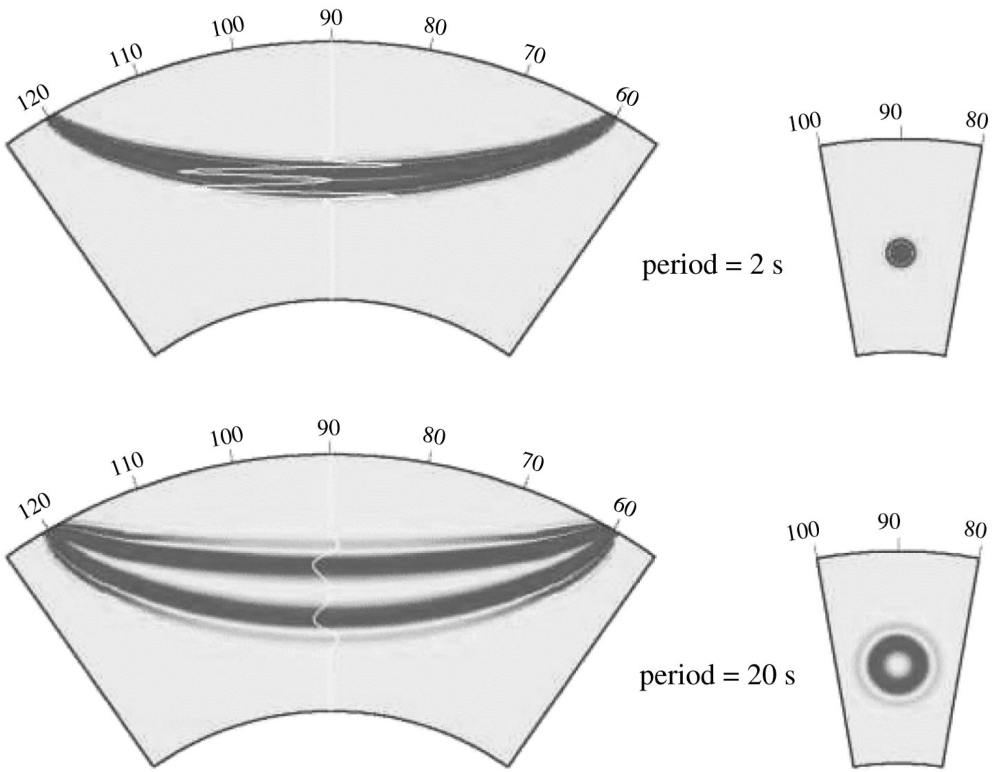
Resolution

- Dominant frequency
- Fresnel zone (velocity, distance, frequency)
- Reflections and vertical resolution

Banana-doughnut kernels
Dahlen et al. (2000)



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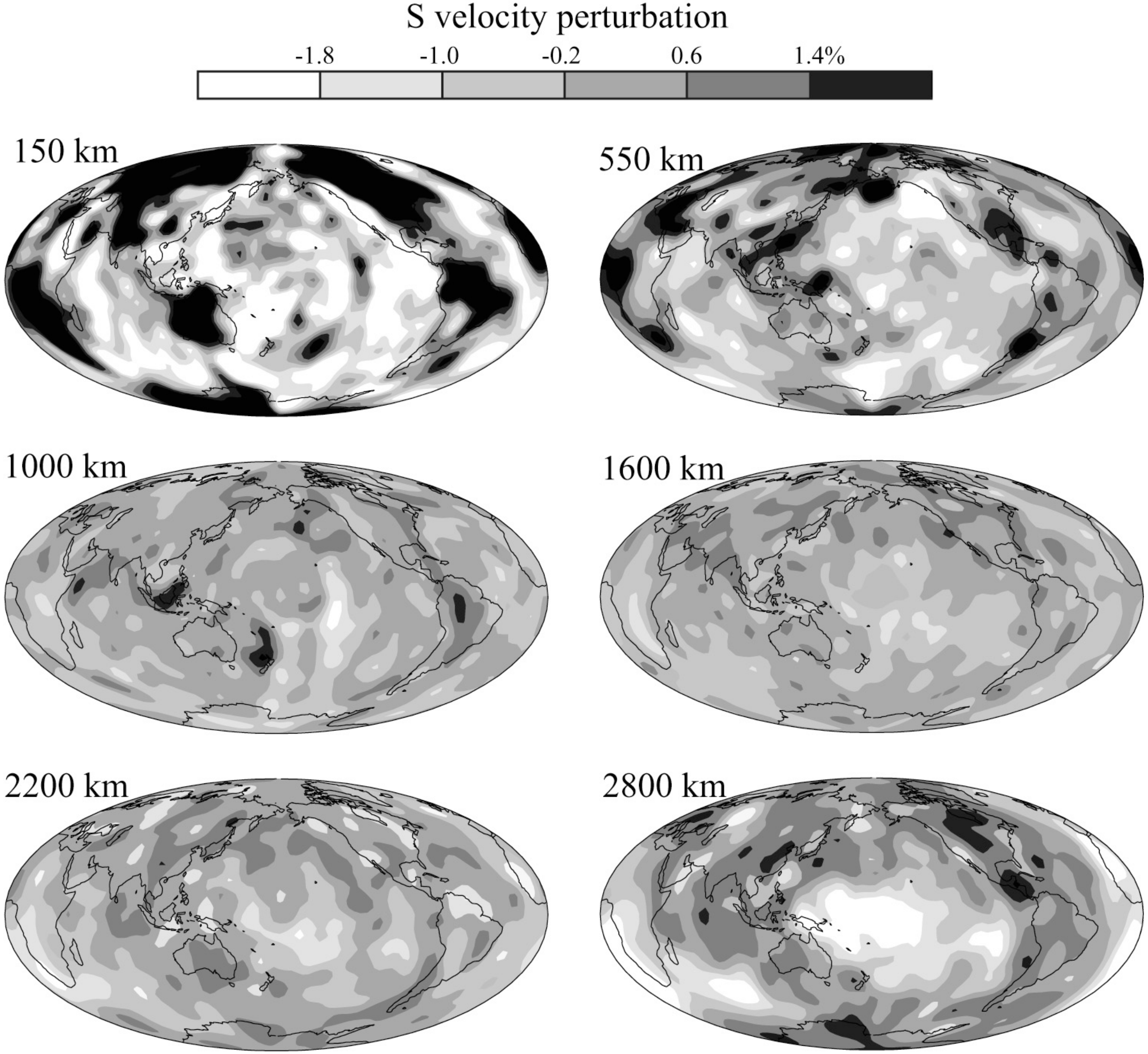
Mantle tomography



Manners and Masters, 2008

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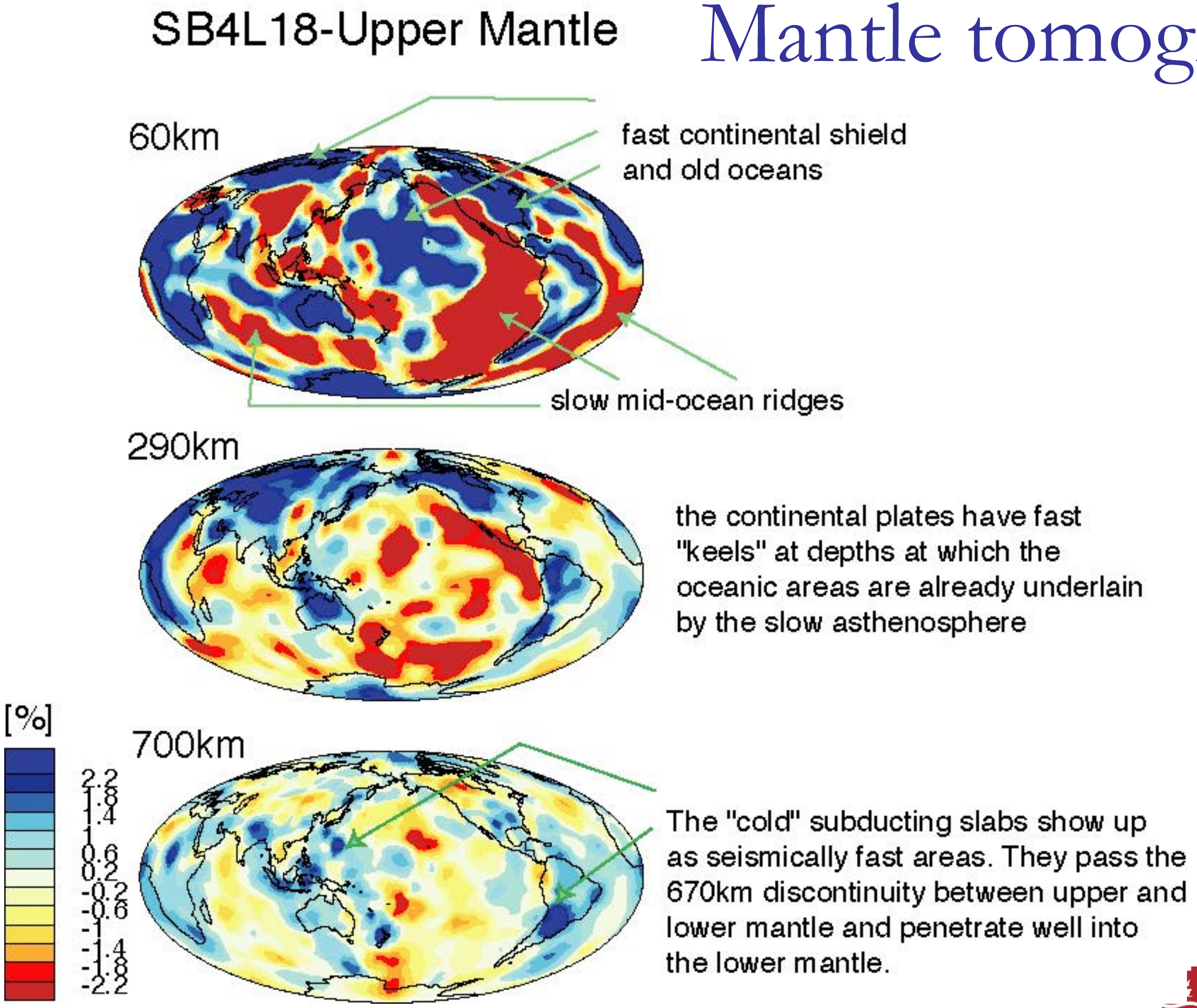
Mantle tomography



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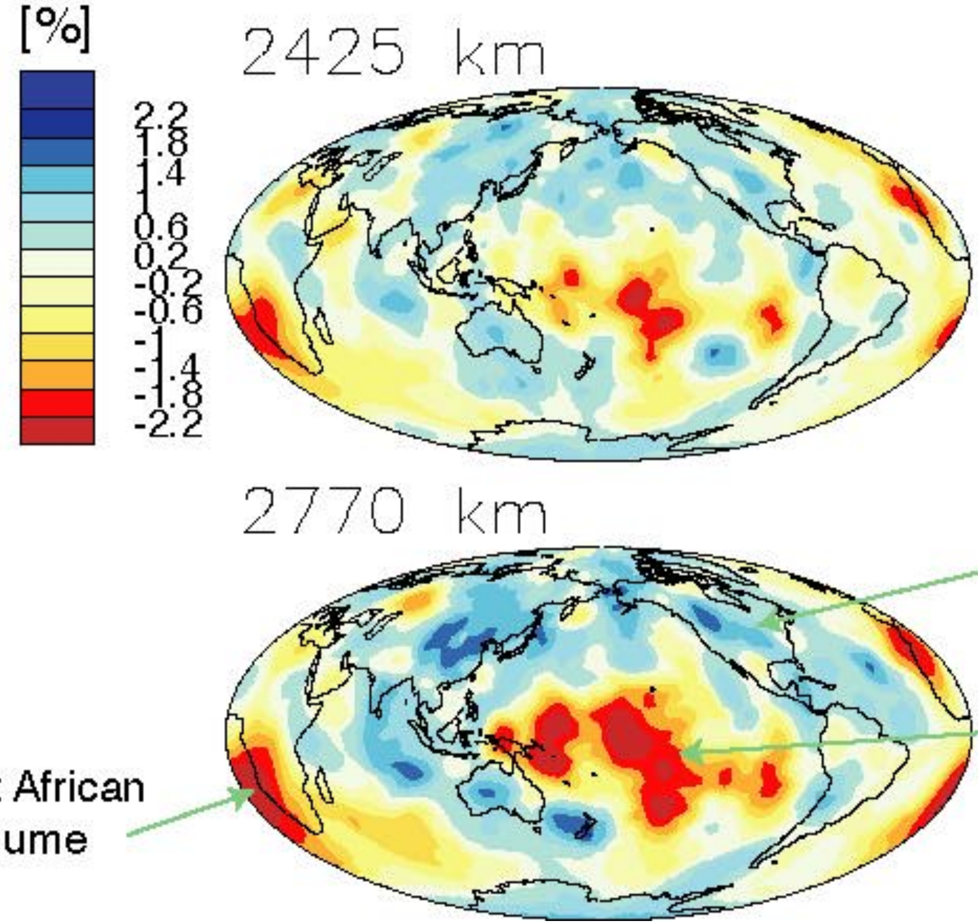
SB4L18-Lowermost Mantle



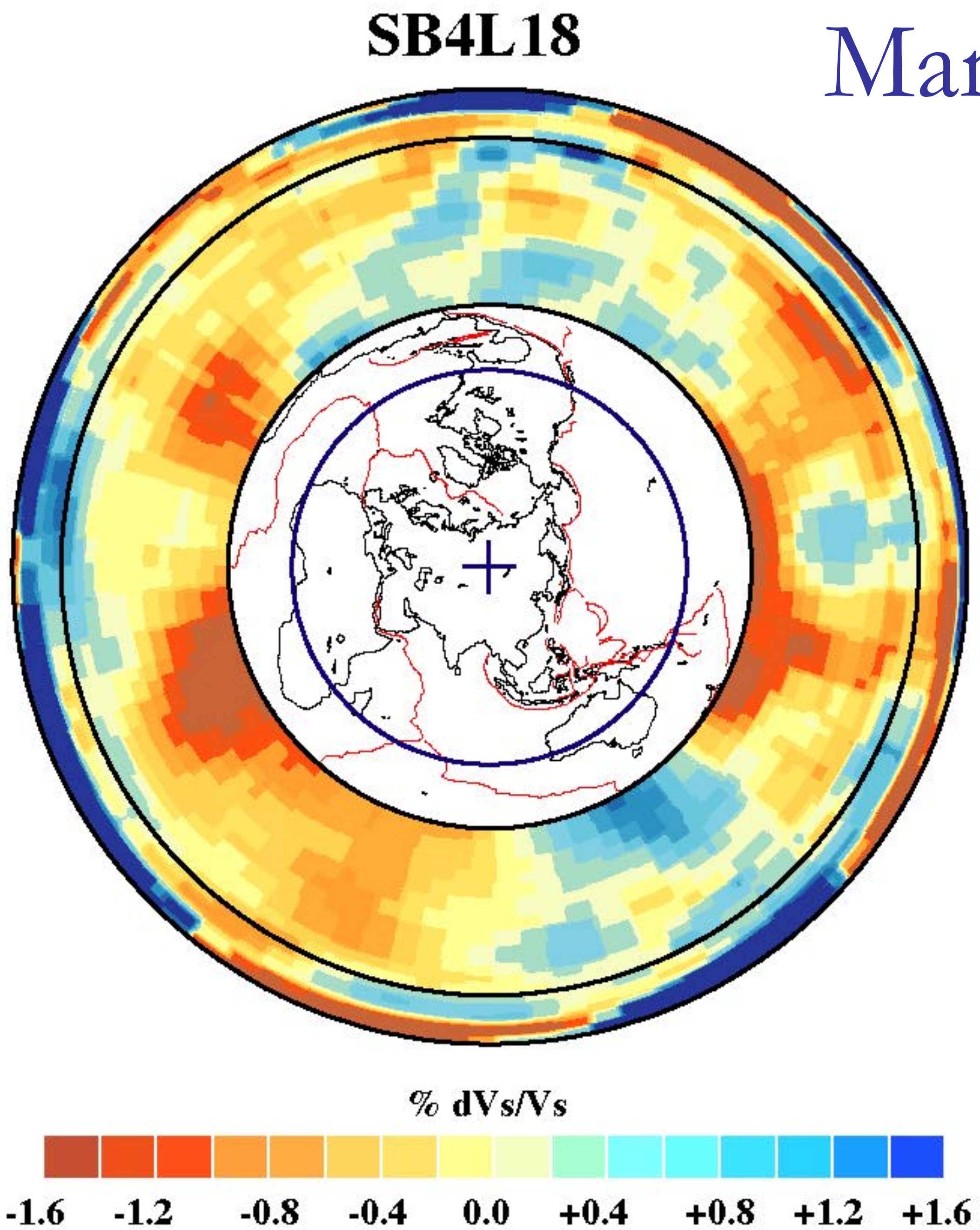
The lowermost mantle is dominated by a ring of "fast" material around the Pacific and "slow" material in the Central Pacific and beneath Africa. The fast regions are thought to be the "graveyard of subducting slabs".

graveyard of slabs

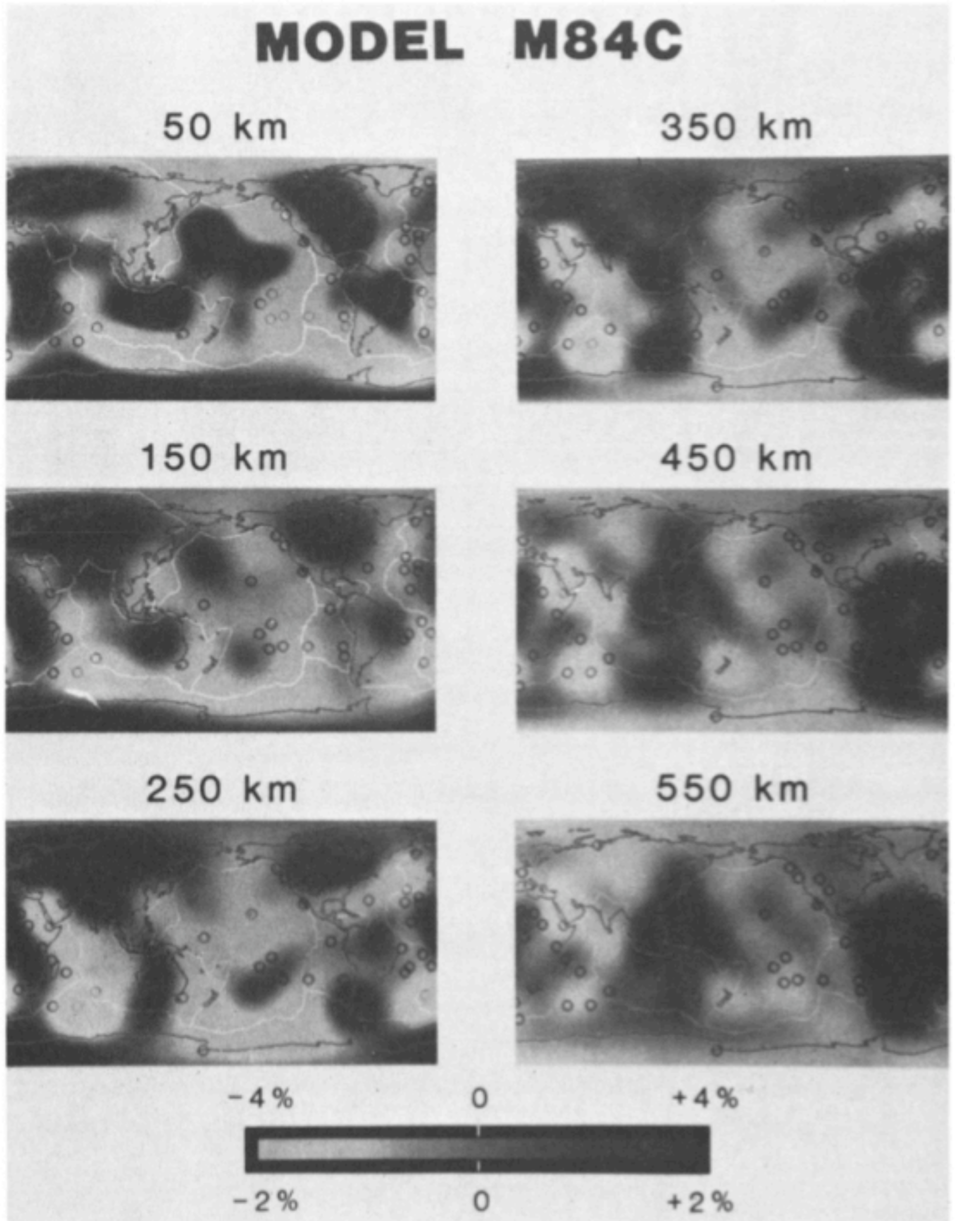
Central Pacific Super Plume

Great African Plume

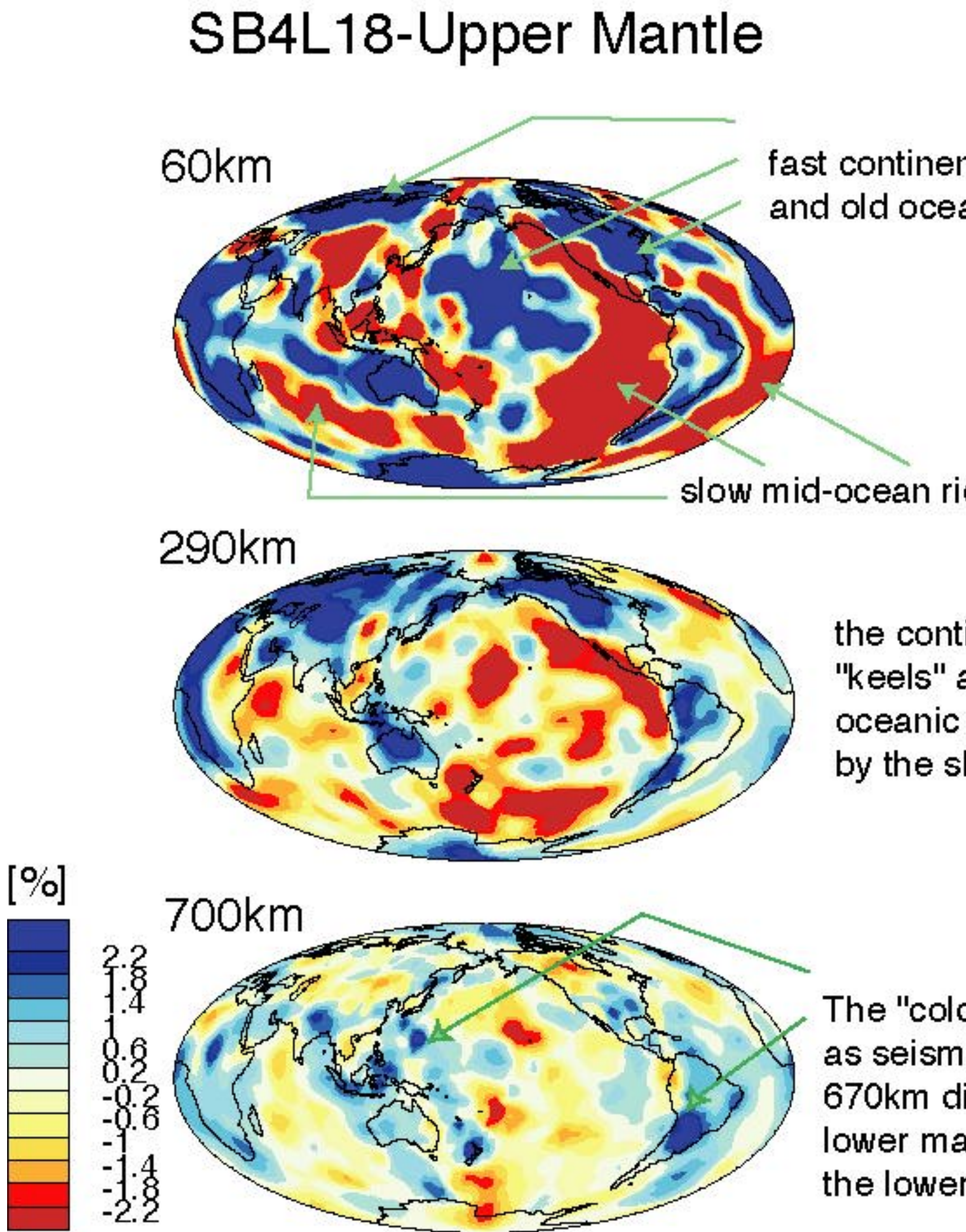
Mantle tomography



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 subduction slabs", whilst the slow regions are looking increasingly like compositionally distinct material.



Dziewonski and Woodhouse, 1984



Masters et al., 2008

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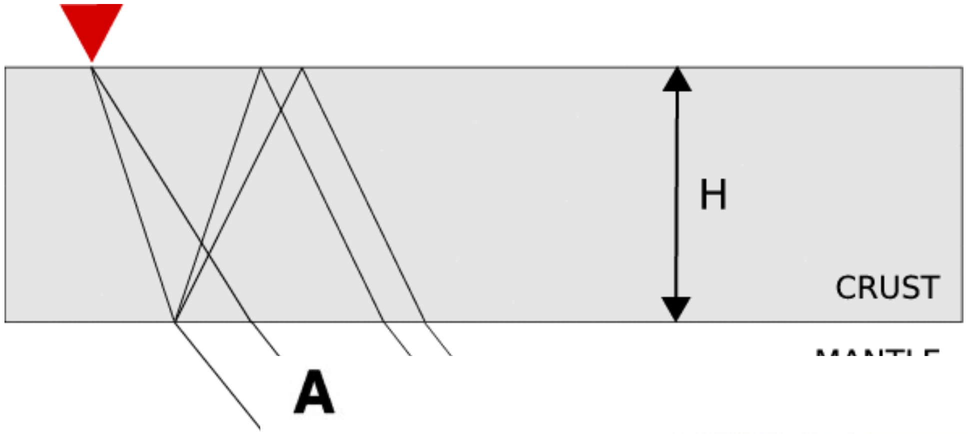
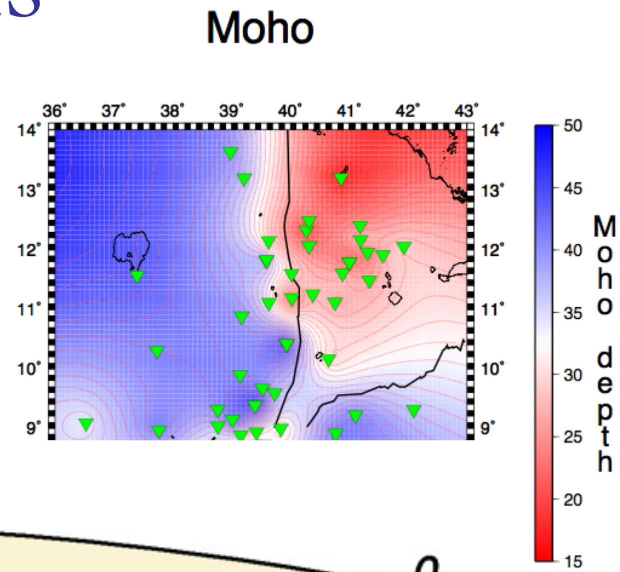
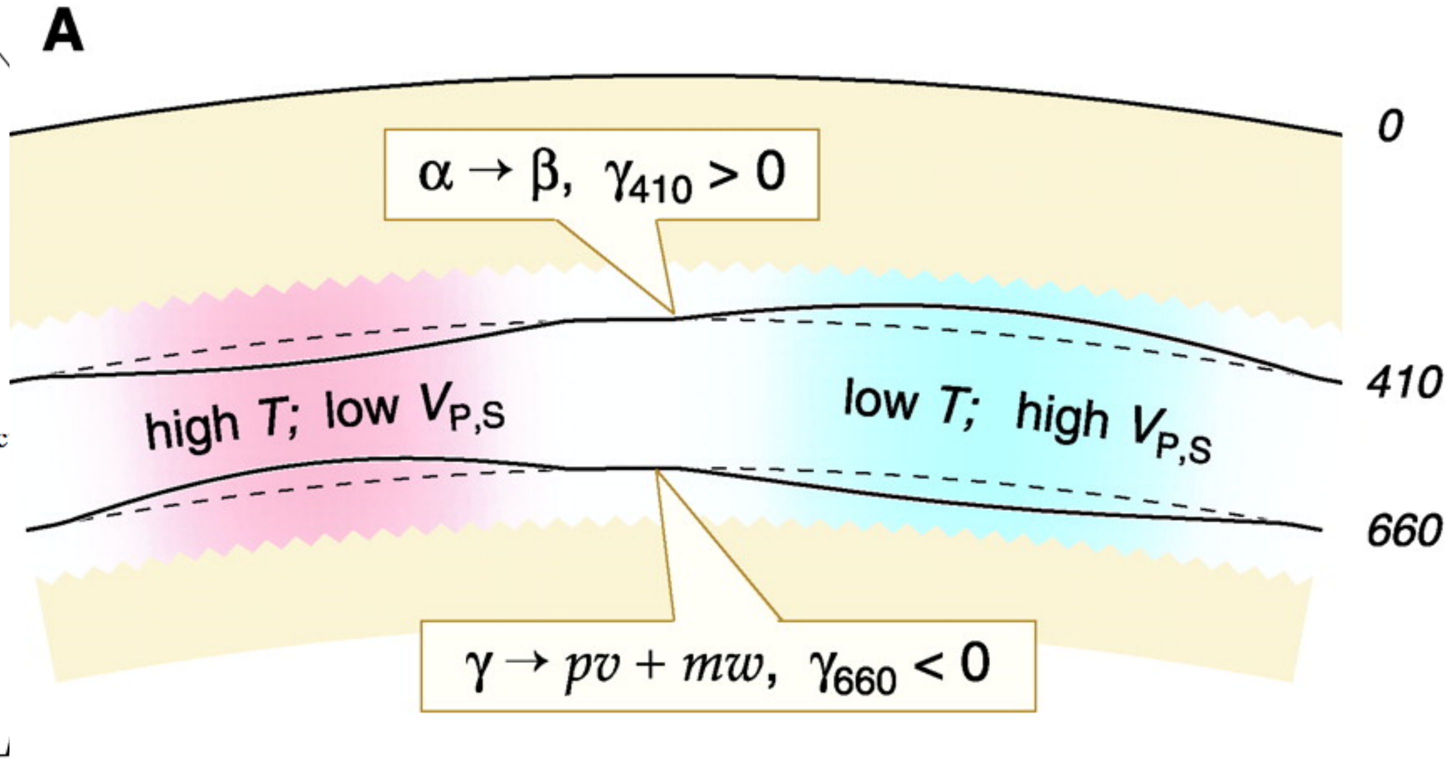
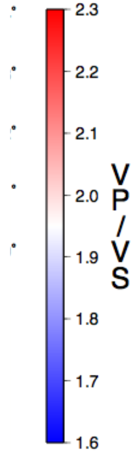
Receiver functions





Direc





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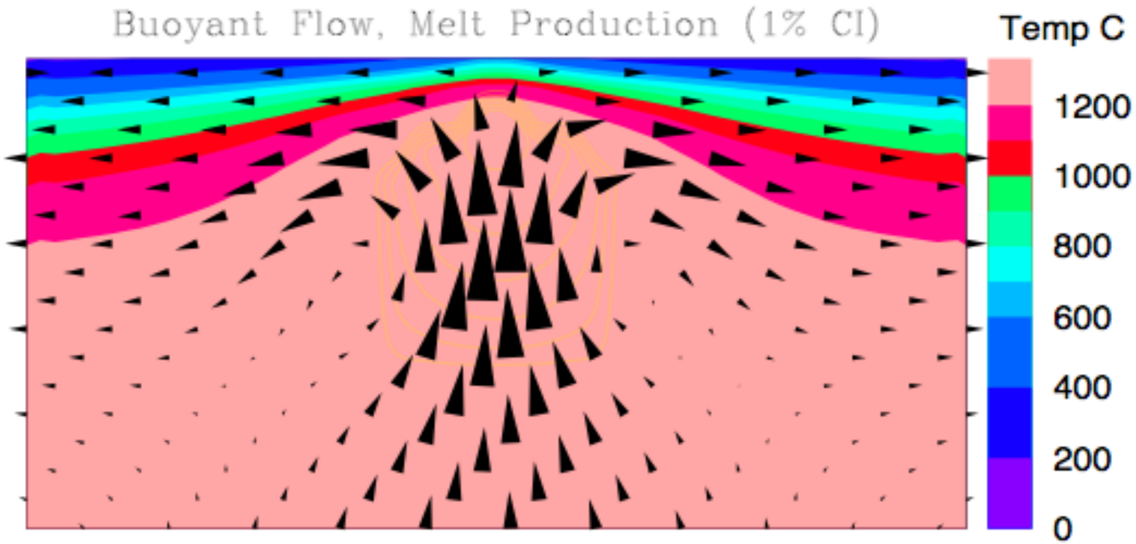
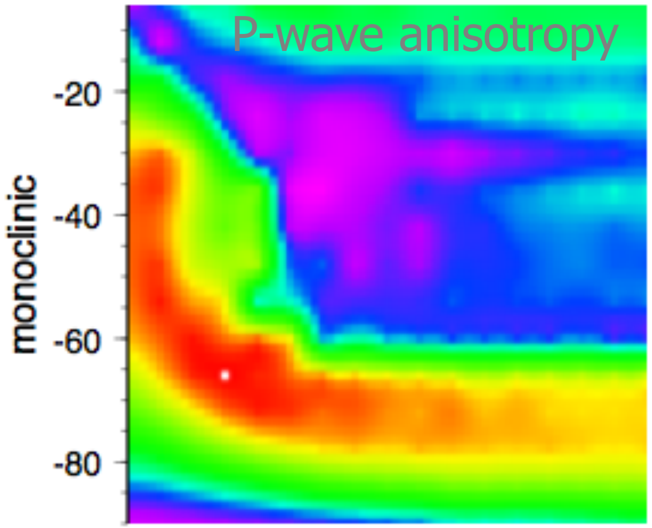
Seismic anisotropy

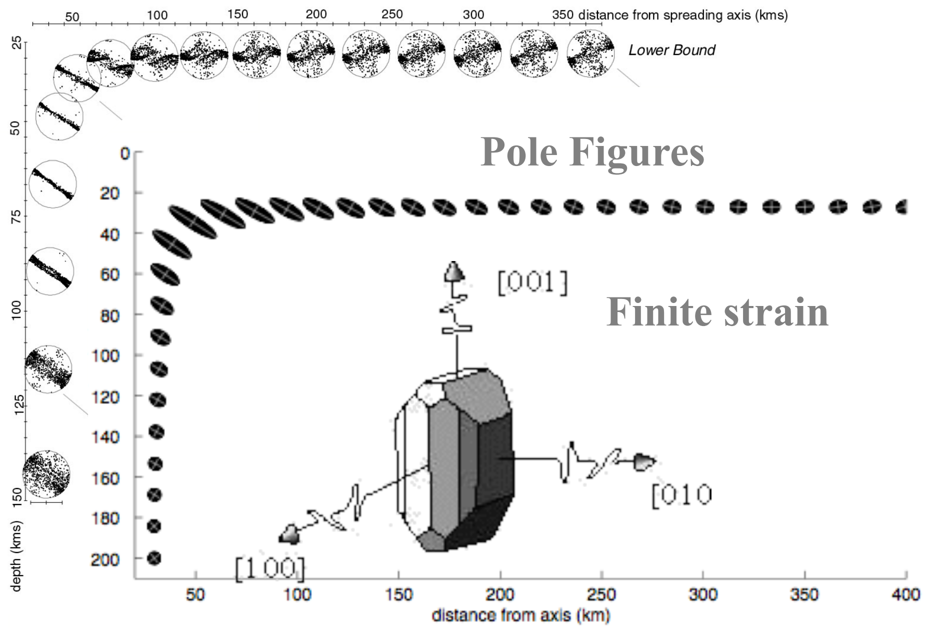


Flow and Temperature

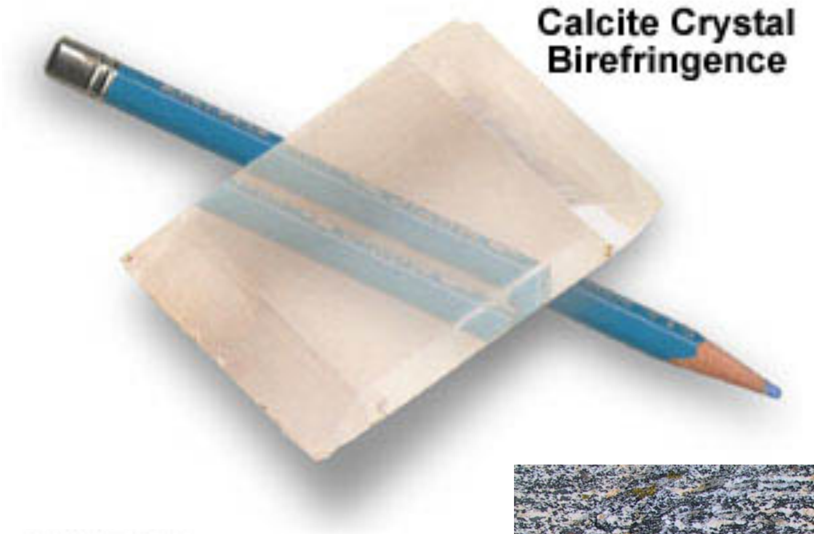
Flow induced olivine alignment.

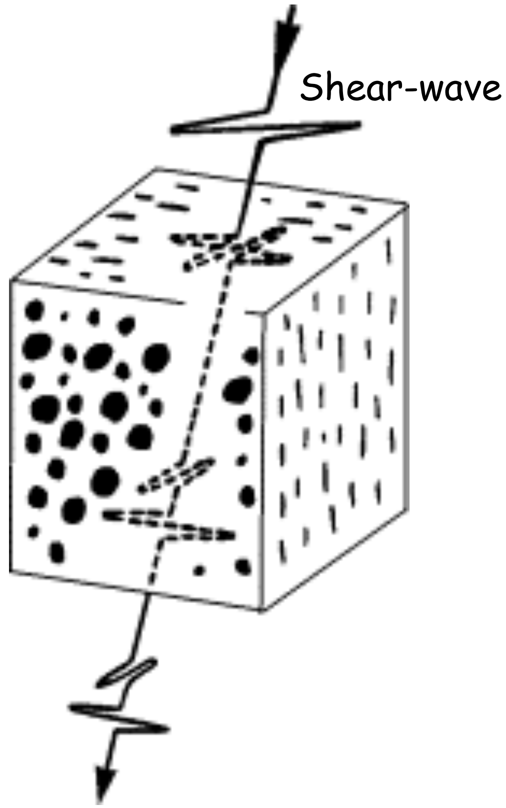
(Blackman and Kendall, 1997;2002)





Imaging the fabric of the Earth: Shear-wave splitting





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Seismic anisotropy: shear-wave splitting

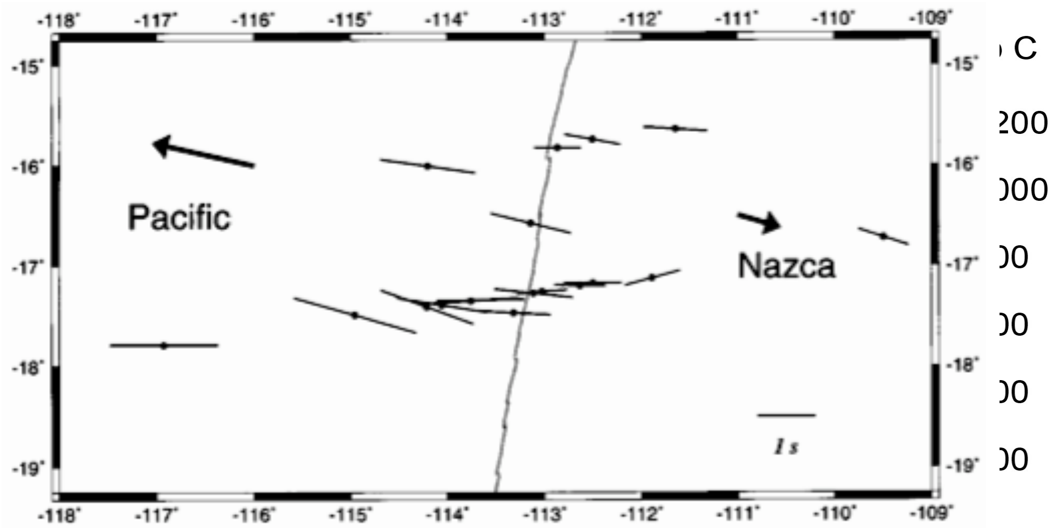
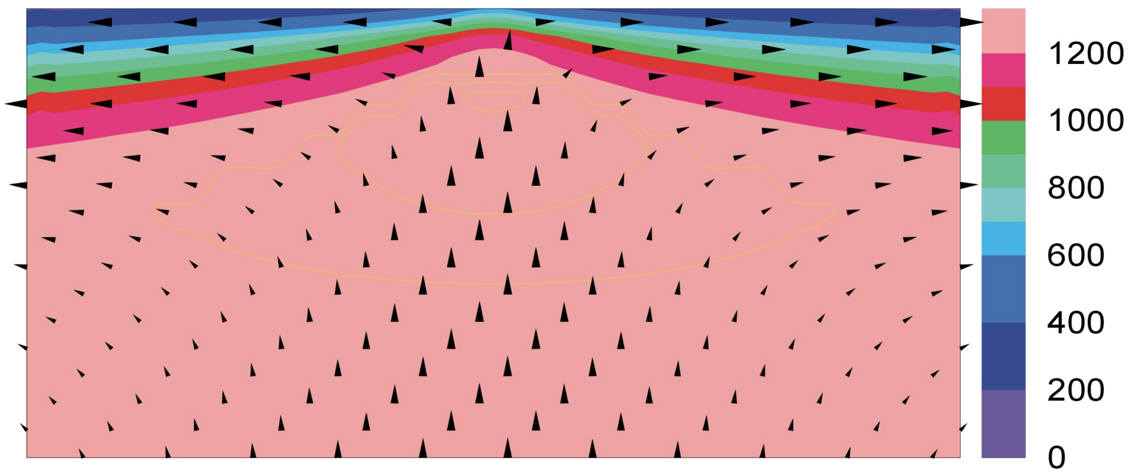


Fig. 3. Shear-wave splitting across the MELT array. Dots denote the position of the OBSs, and solid lines indicate the orientation of the fast direction ϕ, with the line length proportional to the delay time δt between fast and slow shear waves (Table 1). The rise axis is plotted as a solid line. Arrows indicate the magnitude and direction of absolute plate motion (*20*); the directions of absolute plate motion (*20*) and relative plate motion (*12*) are identical to within a few degrees in this region.

Wolfe and Silver, 1998

2.5D spreading center: Flow rift perpendicular



1.8 mm/yr

Model predicts rift-perpendicular orientation off-axis (large dt).

Blackman and Kendall 1996; 1997; 2002a,b

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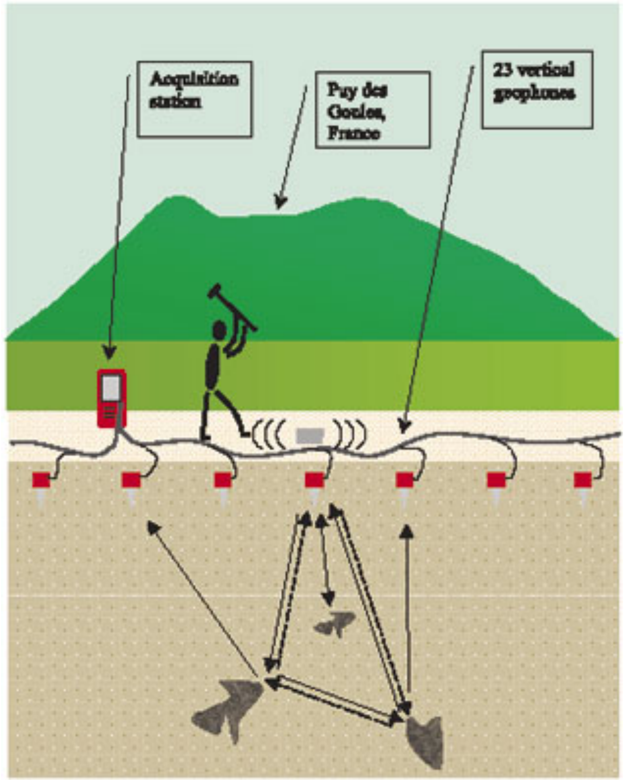
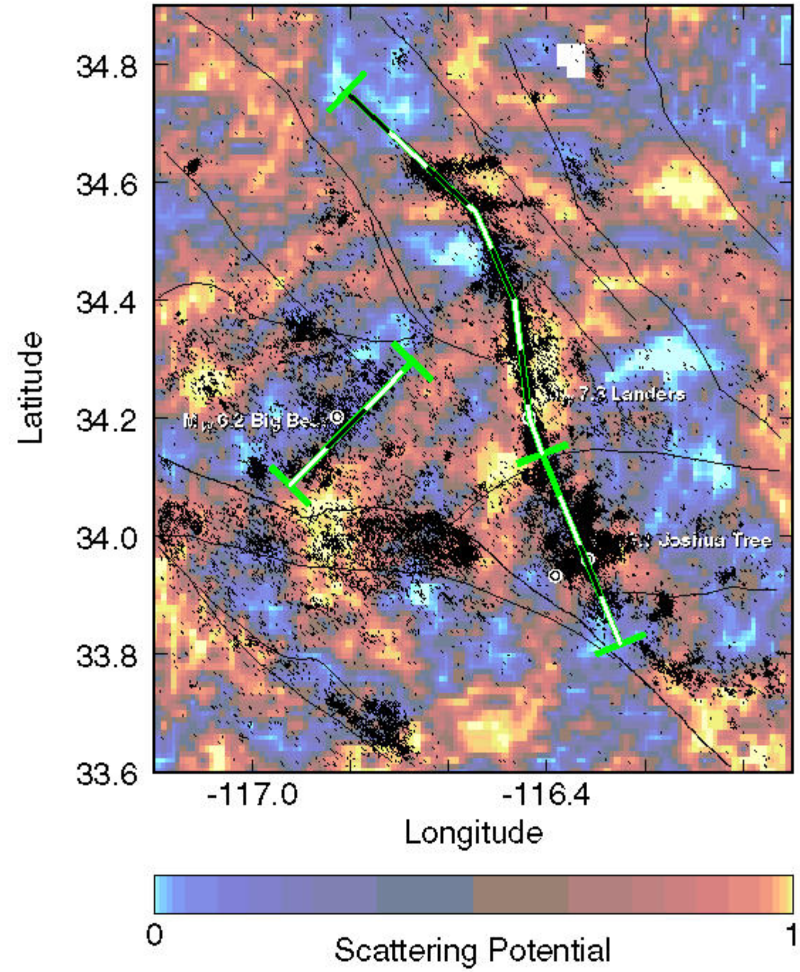
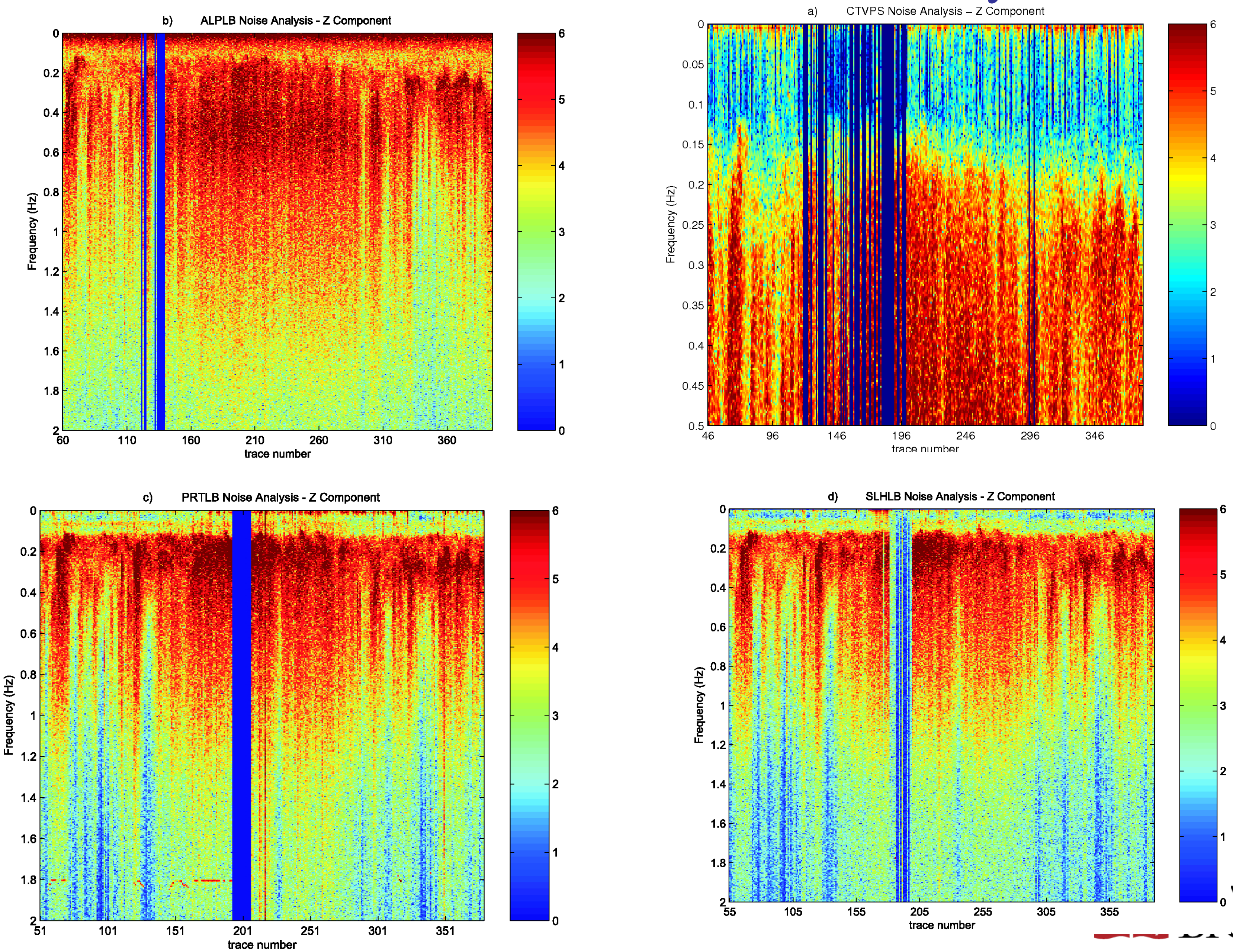
Scattering from faults, cracks, asperities





Noise interferometry



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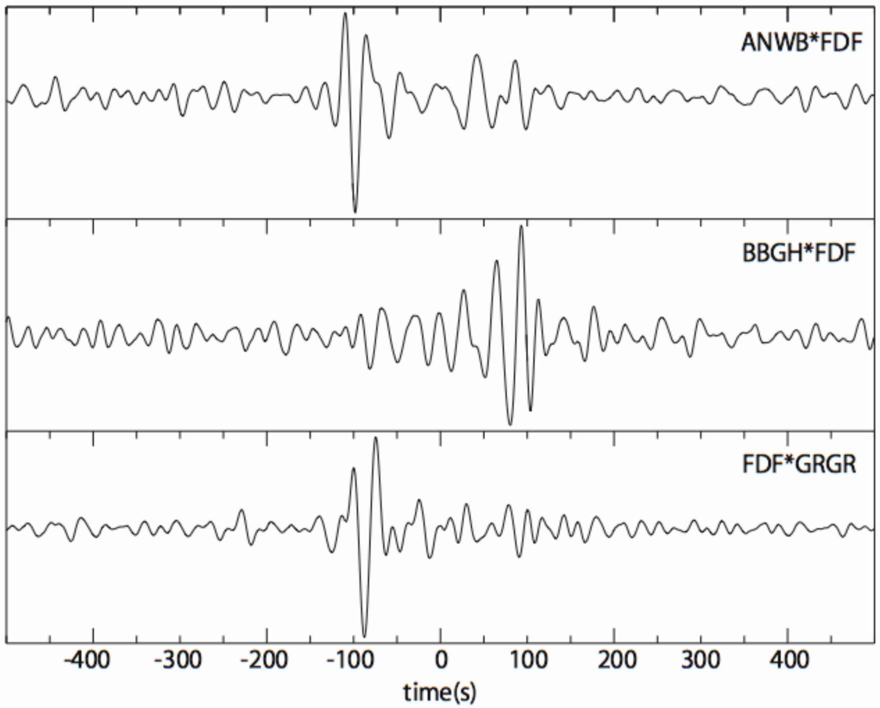
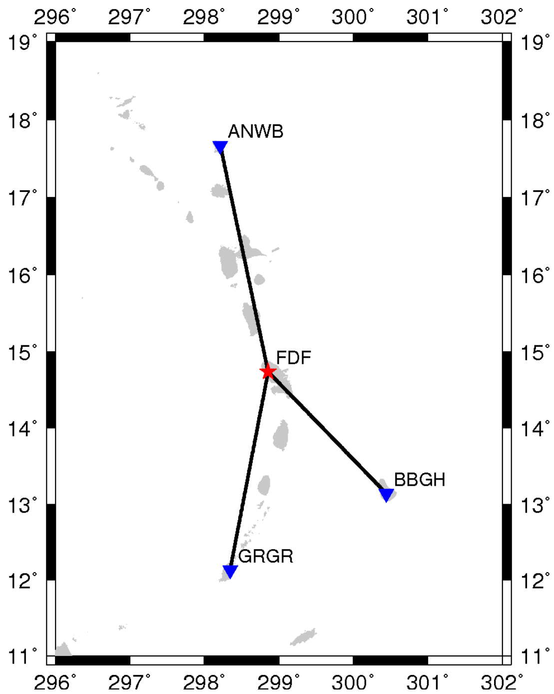
ISTOL

Noise correlation: Interstation Green's functions





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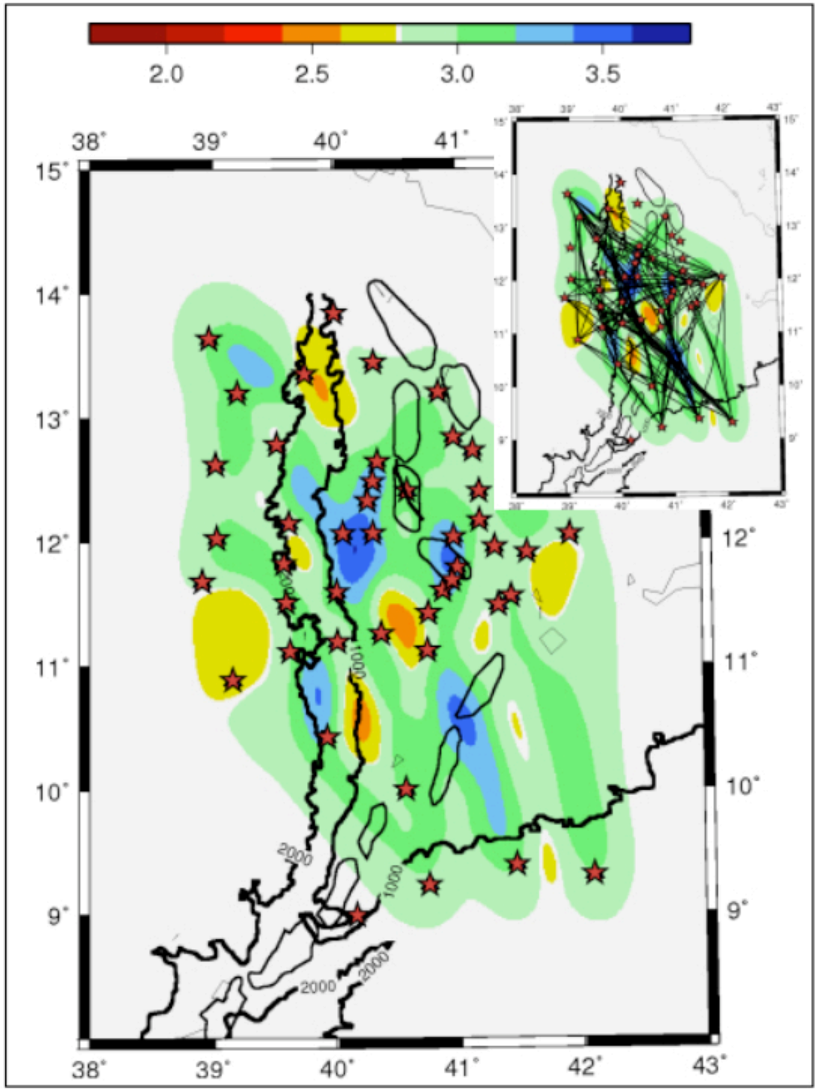
Lithospheric velocities



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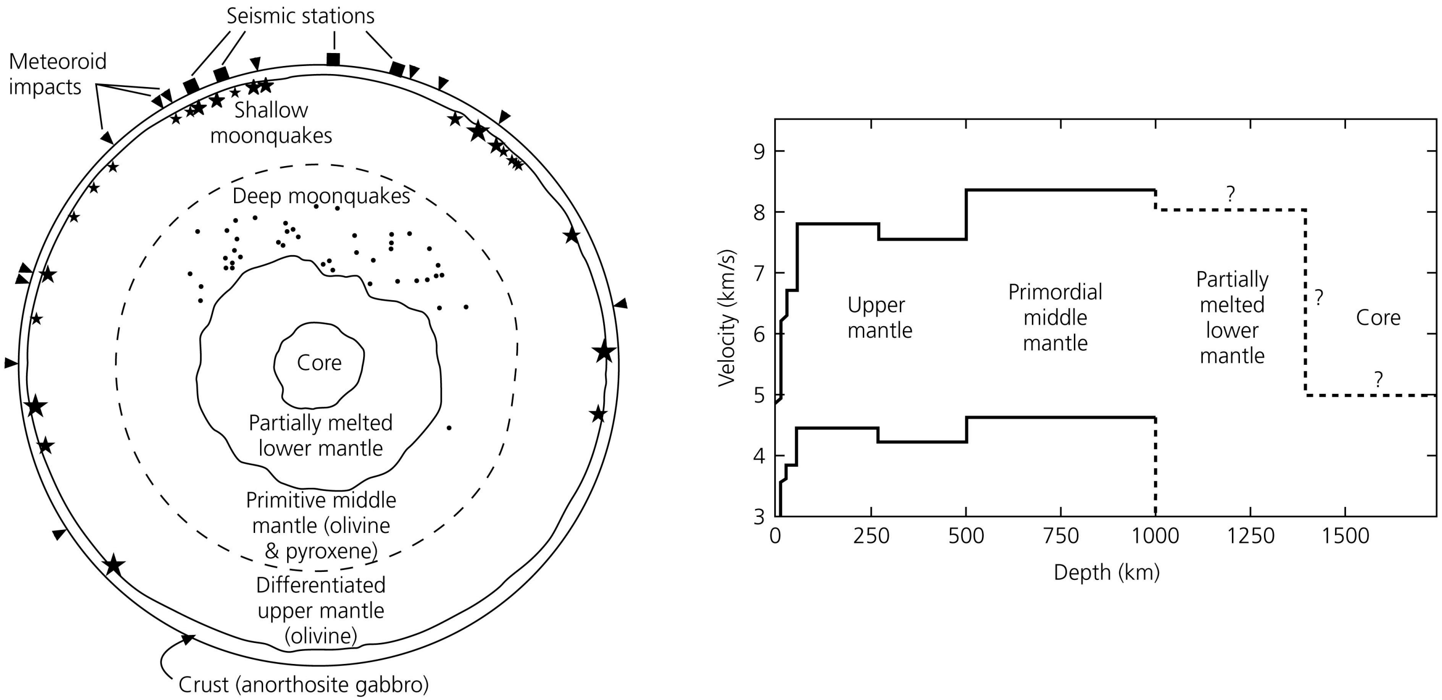
The moon and beyond

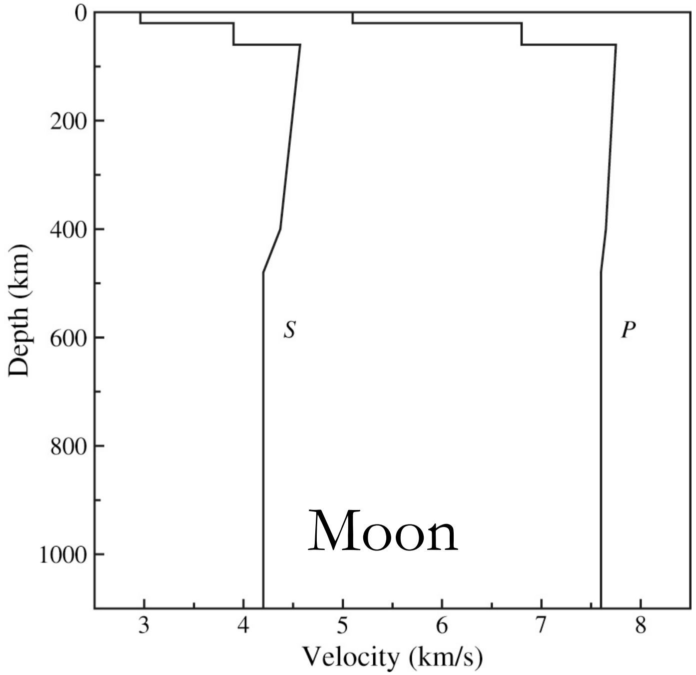
- Moon - quiet environment; low detection thresholds.
- Mars - atmospheric noise; modes.

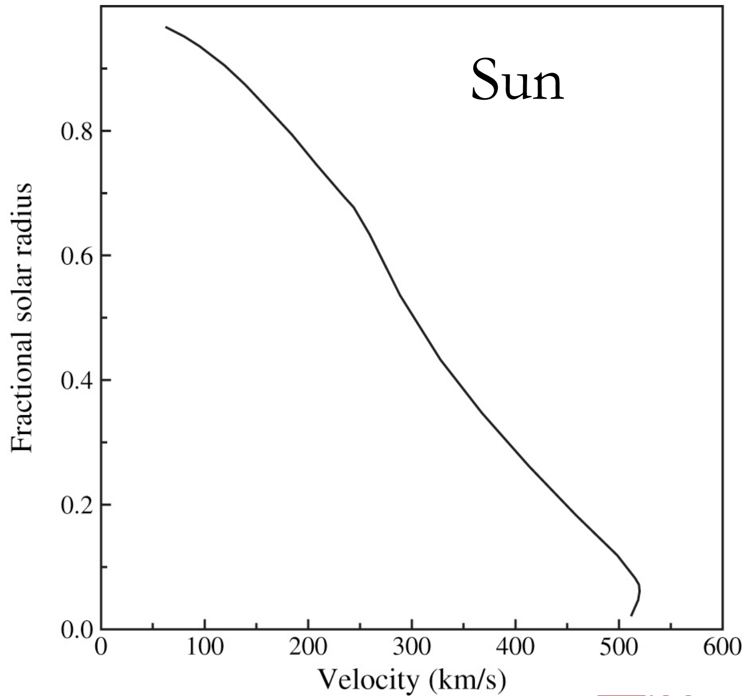
Figure 3.8-17: Cartoon and velocity model for the moon.



The moon and beyond

- Moon - quiet environment; low detection thresholds.
- Sun - helioseismology; trapped acoustic waves measured by Doppler shift in spectral line.





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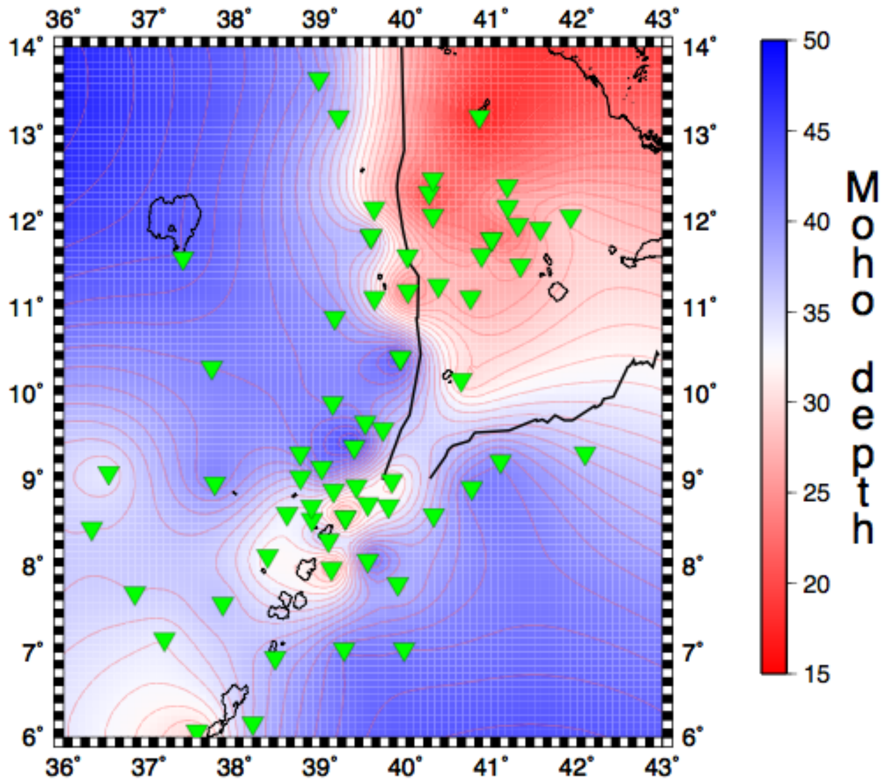
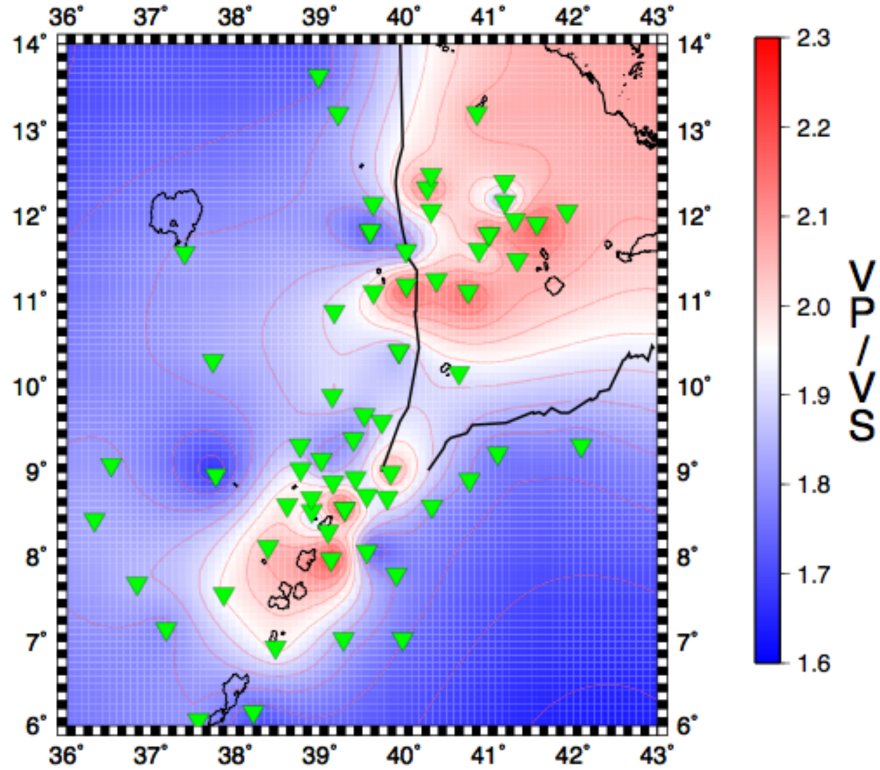
Moho



VP/VS



Hammond et al., 2010

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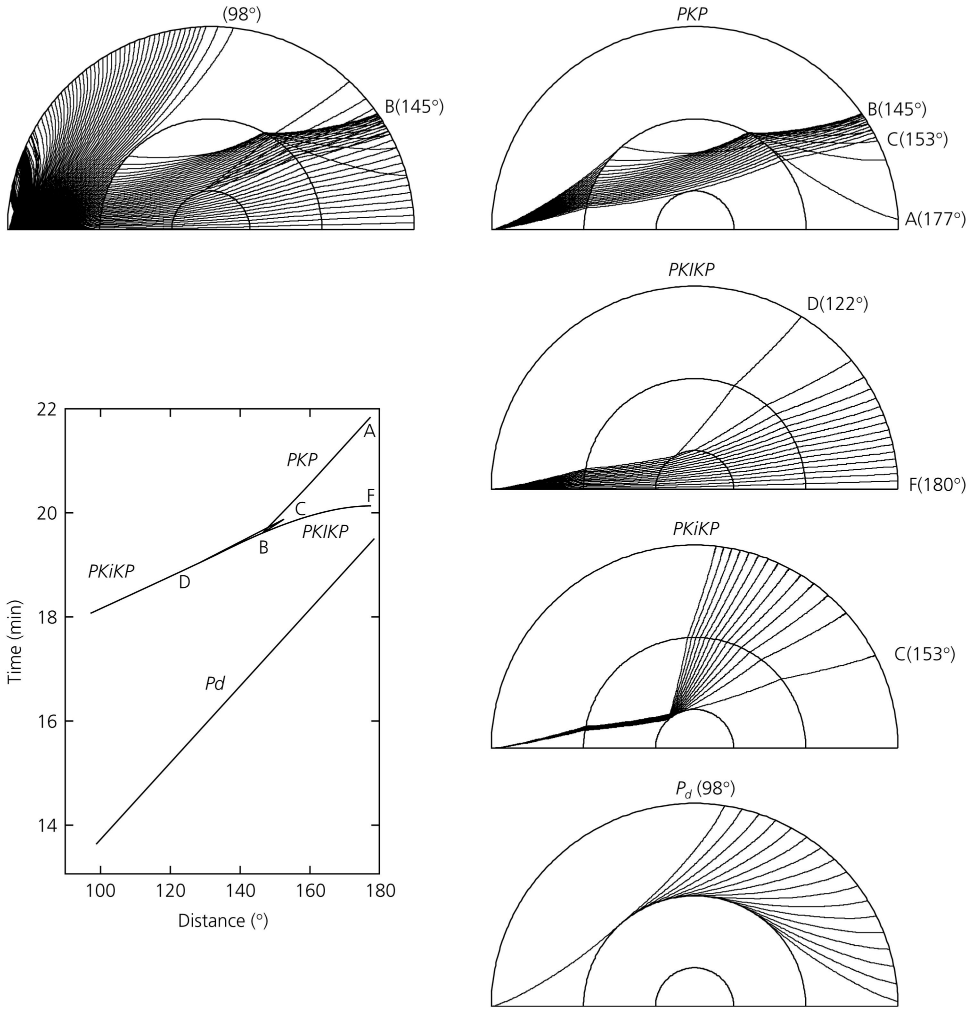
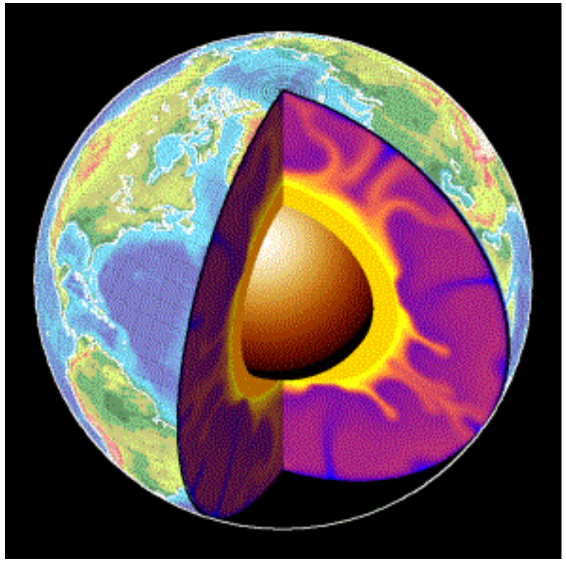
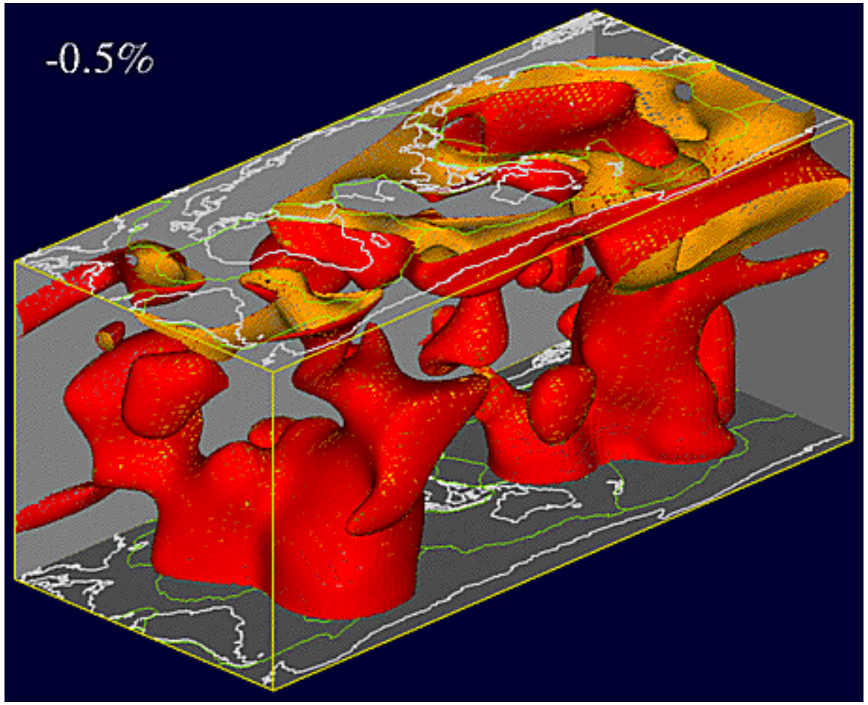
Figure 3.5-7: Ray paths and travel times for major core phases.



Seismology allows us to 'see' inside the Earth.





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