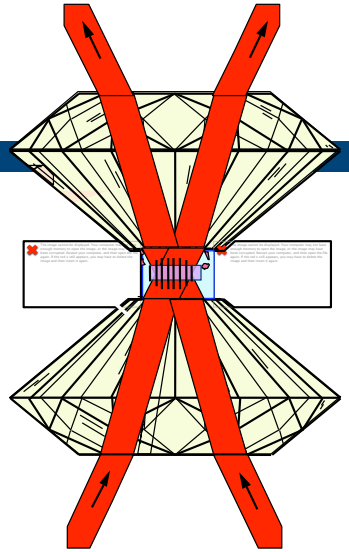
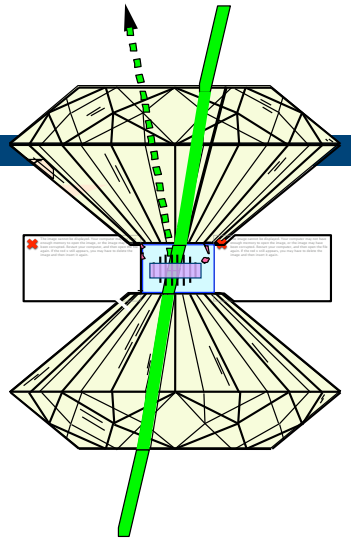
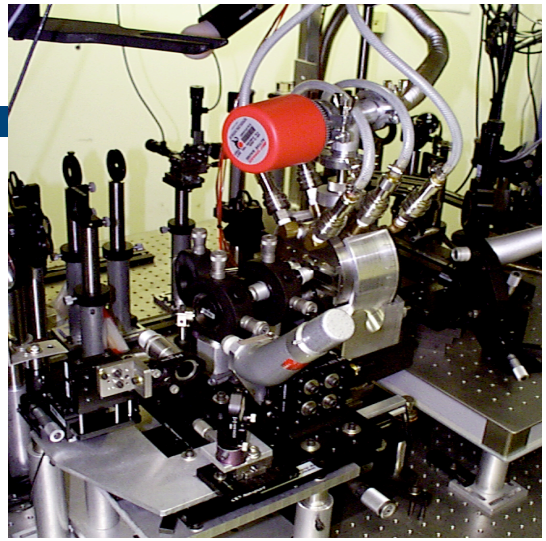
Using Seismic Waves As Earth Probes

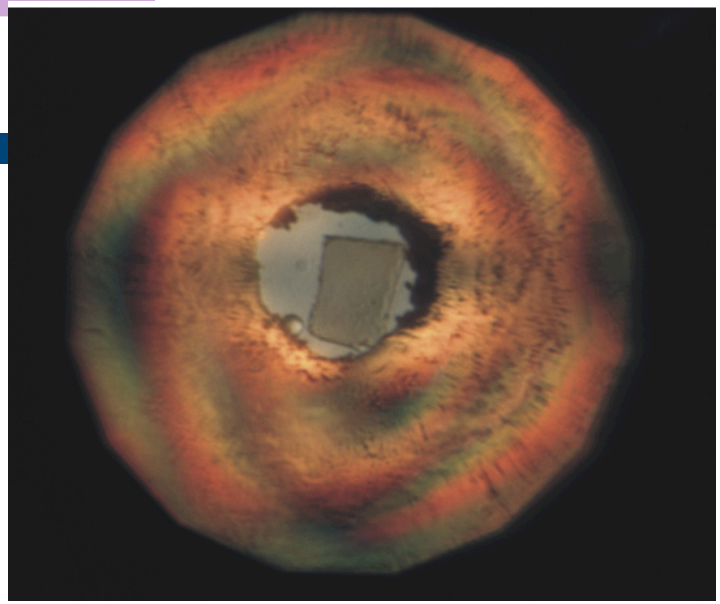
- Seismic waves determine velocities and densities of the unseen parts of the crust, mantle, and core.
- Velocities and densities change much with depth
  - both gradual change and discontinuities
- Lateral changes are smaller
  - But contain important clues to composition and temperatures
- Laboratory data (velocities and densities measured at high pressure and temperature) are needed to interpret the seismic data.

Diamond Anvil Cells: mantle and core conditions of pressure and temperatures in the lab









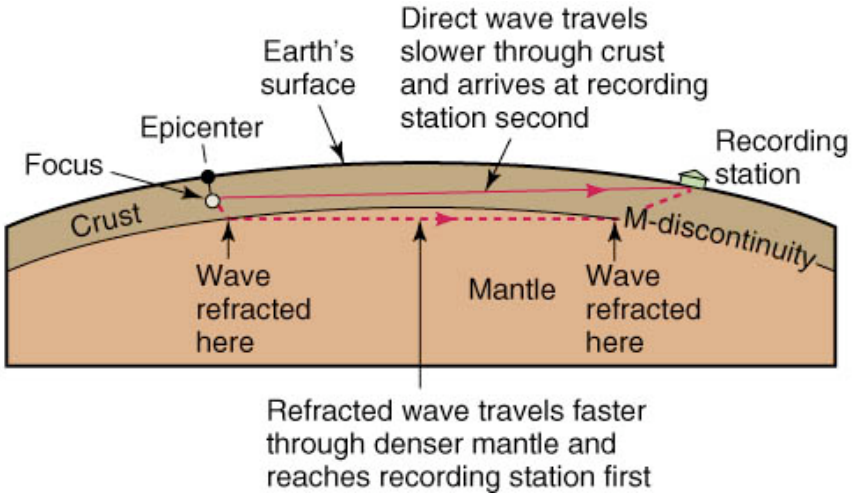

Direct wave travels slower through crust and arrives at recording station second
Earth's surface
Epicenter
Focus
Recording station
Crust
M-discontinuity
Wave refracted here
Mantle
Wave refracted here
Refracted wave travels faster through denser mantle and reaches recording station first

Figure 10.22

Using Seismic Waves As Earth Probes

- Early in the twentieth century, the boundary between Earth's crust and mantle was demonstrated by a Croatian scientist named Mohorovicic.
- A distinct compositional boundary separated the crust from this underlying zone of different composition (the Mohorovicic discontinuity).
- Seismic wave speeds can be measured for different rock types in both the laboratory and the field.

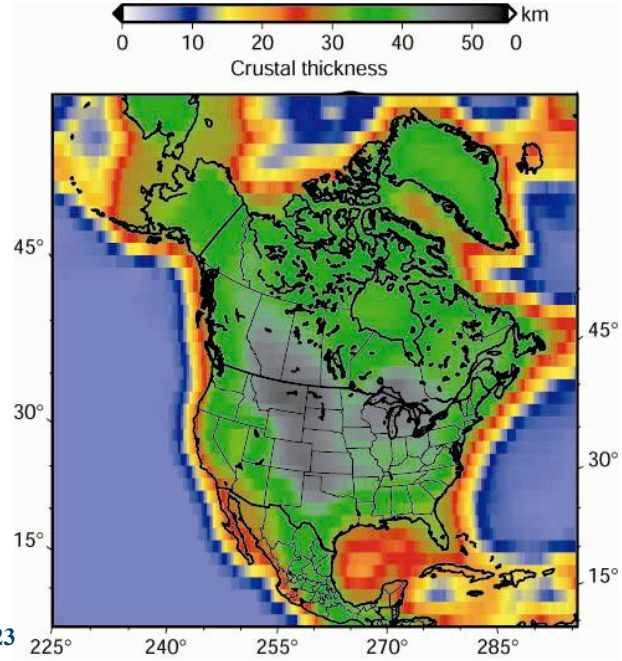


Figure 10.23

Using Seismic Waves As Earth Probes

- The thickness and composition of continental crust vary greatly from place to place.
  - Thickness ranges from 20 to nearly 70 km and tends to be thickest beneath major continental collision zones, such as Tibet.
- P-wave speeds in the crust range between 6 and 7 km/s. Beneath the Moho, speeds are greater than 8 km/s.

Using Seismic Waves As Earth Probes

- Laboratory tests show that rocks common in the crust, such as granite, gabbro, and basalt, all have P-wave speeds of 6 to 7 km/s.
- Rocks that are rich in dense minerals, such as olivine, pyroxene, and garnet, have speeds greater than 8 km/s.
  - Therefore, the most common such rock, called peridotite, must be among the principal materials of the mantle.

Using Seismic Waves As Earth Probes

- Some evidence can be obtained from rare samples of mantle rocks found in kimberlite pipes—narrow pipe-like masses of intrusive igneous rock, sometimes containing diamonds, that intrude the crust but originate deep in the mantle.

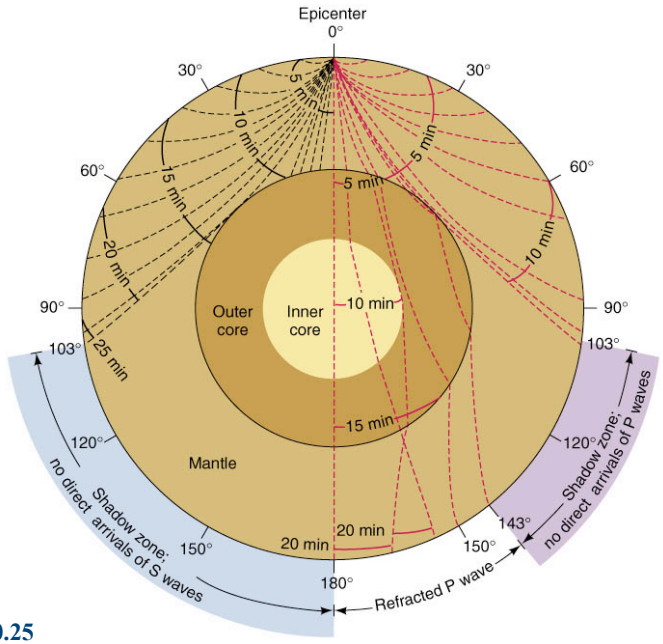


Figure 10.25

Using Seismic Waves As Earth Probes

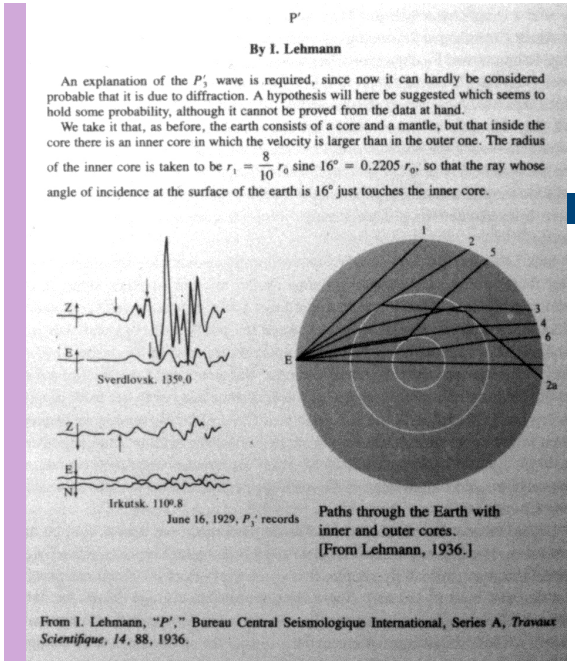
- Both P and S waves are strongly influenced by a pronounced boundary at a depth of 2900 km.
  - boundary between the mantle and the core.
- Rock density increases from about 3.3 g/cm^3 at the top of the mantle to about 5.5 g/cm^3 at the base of the mantle.

Using Seismic Waves As Earth Probes

- The outer core has a density ranging from 10 to 13 g/cm^3 and velocity from 8 to 10 km/s
- The only material that fits these velocities and densities is iron mixed with about 10% of lighter elements

Using Seismic Waves As Earth Probes

- Iron meteorites are samples of material believed to have come from the core of ancient, tiny planets, now disintegrated.
- All iron meteorites contain a little nickel; thus, Earth's core presumably does too.
- P-wave reflections indicate the presence of a solid inner core enclosed within the molten outer core.



P′

By I. Lehmann

An explanation of the P_3' wave is required, since now it can hardly be considered probable that it is due to diffraction. A hypothesis will here be suggested which seems to hold some probability, although it cannot be proved from the data at hand.

We take it that, as before, the earth consists of a core and a mantle, but that inside the core there is an inner core in which the velocity is larger than in the outer one. The radius of the inner core is taken to be $r_1 = \frac{8}{10} r_0 \sin 16° = 0.2205\, r_0$, so that the ray whose angle of incidence at the surface of the earth is 16° just touches the inner core.

Z
E
Sverdlovsk. 135ᵐ.0
Z
E
N
Irkutsk. 110ᵐ.8
June 16, 1929, P_3' records

1 2 5 3 4 6 E 2a

Paths through the Earth with inner and outer cores. [From Lehmann, 1936.]

From I. Lehmann, "*P*′," Bureau Central Seismologique International, Series A, *Travaux Scientifique*, *14*, 88, 1936.

Inge Lehmann (1888-1993)

She noted that she grew up in Denmark not knowing that girls were not supposed to be scientists

1936 paper wins award for shortest title:
P'

Layers of Different Physical Properties in the Mantle

- The P-wave velocity at the top of the mantle is about 8 km/s and it increases to 14 km/s at the core-mantle boundary.
- The low-velocity zone can be seen as a small blip in both the P-wave and S-wave velocity curves.
  - An integral part of the theory of plate tectonics is the idea that stiff plates of lithosphere slide over a weaker zone in the mantle called the asthenosphere.
  - In the low velocity zone rocks are closer to their melting point than the rock above or below it.

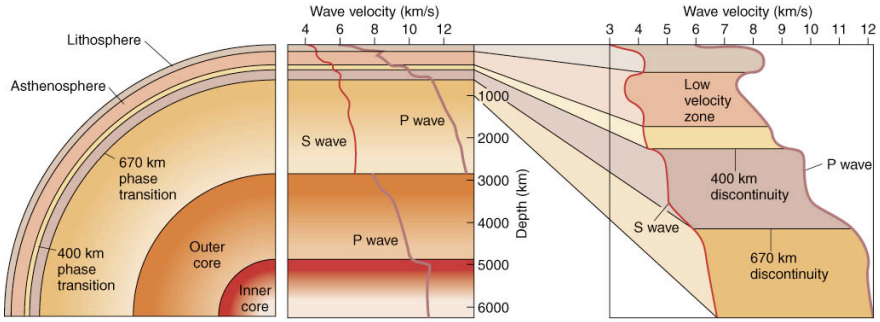
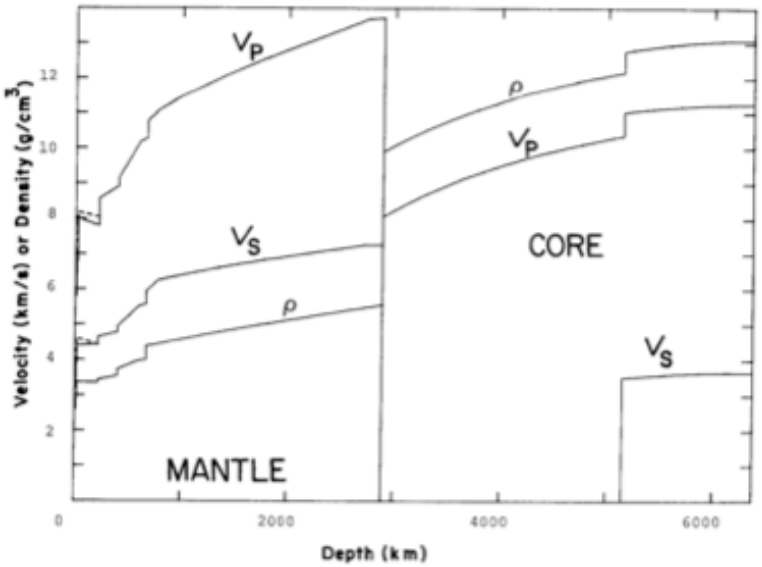


Figure 10.26

Seismic 1-D Earth Model



The 400-km Seismic Discontinuity

- From the P-and S-wave curves, velocities of both P and S waves increase with an 8% jump at about 400 km.
- When olivine is squeezed at a pressure equal to that at a depth of 400 km, the atoms rearrange themselves into a denser polymorph (polymorphic transition).

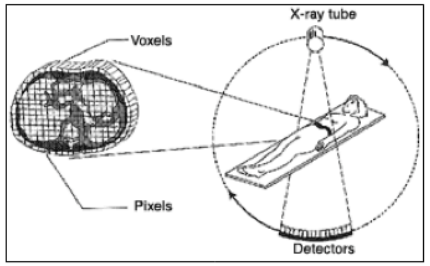
The 670-km Seismic Discontinuity

- Another discontinuity in seismic-wave velocities occurs at a depth of 670 km.
- The 670-km discontinuity corresponds to the pressure of a phase transition to a still denser silicate polymorph.

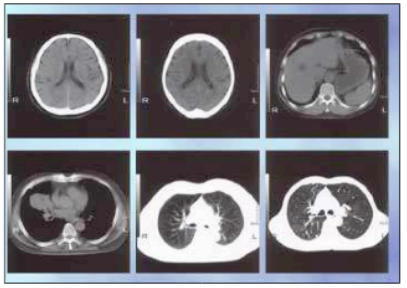
Seismic Waves and Heat

- Seismic wave speed is affected by temperature.
- Seismologists translate travel-time discrepancies into maps of ‘fast” and “slow” regions of Earth’s interior using seismic tomography.

X-Ray attenuation tomography

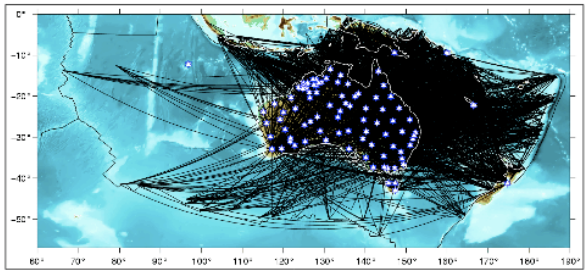


Projections from all angles:
X-ray intensity

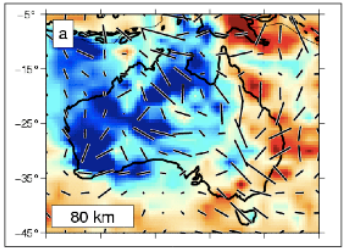


Reconstructed image:
X-ray attenuation constants

Seismic wavespeed tomography

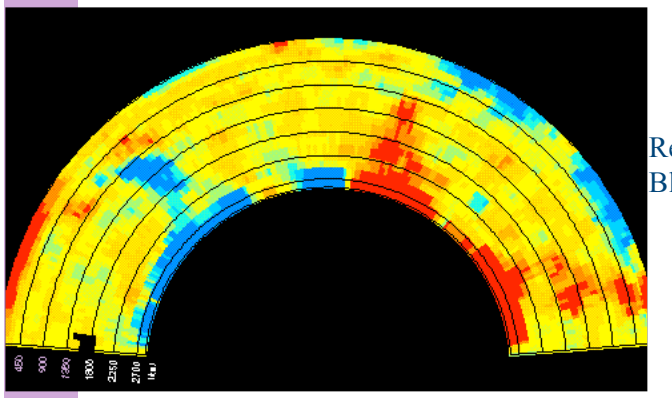


Projections from all angles:
Waveforms and arrival times

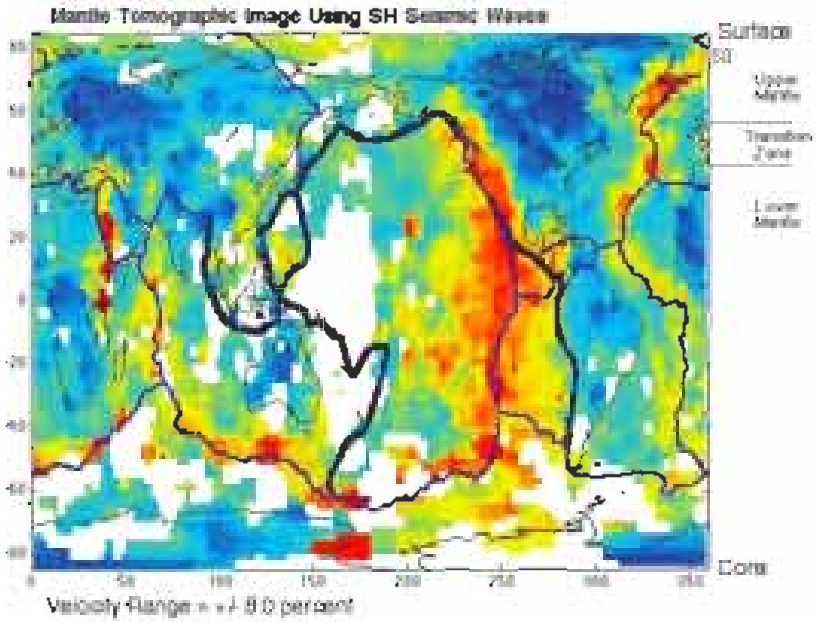


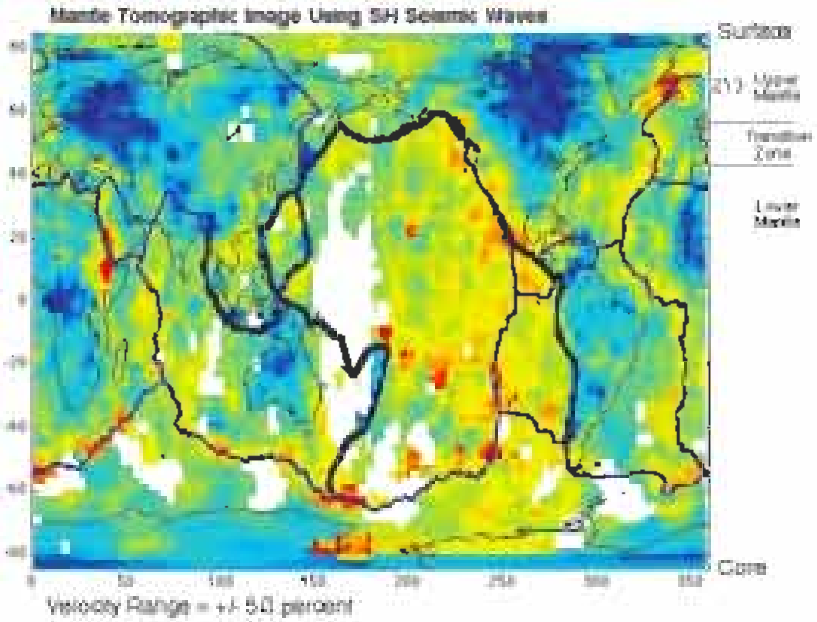
Reconstructed image:
Wavespeed variations

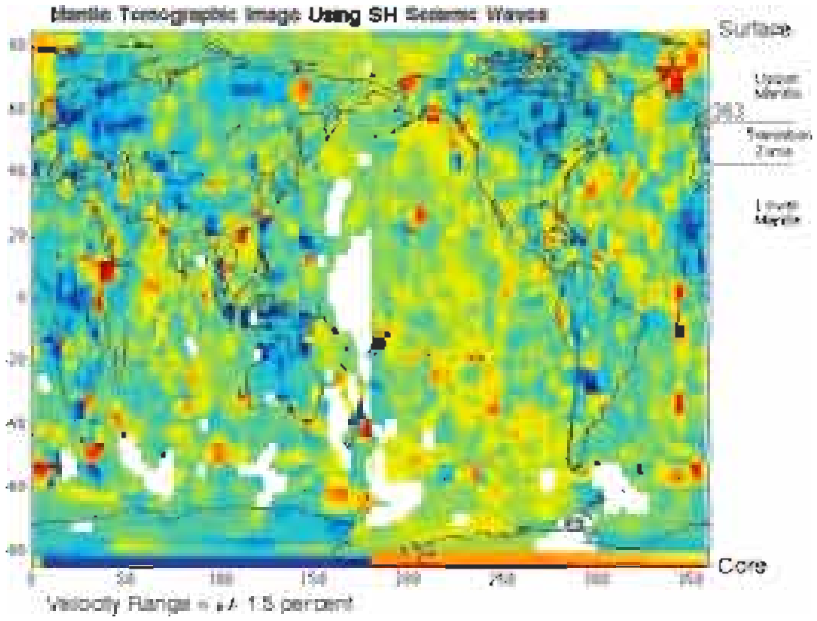
Seismic tomography cross section from Central America through Africa

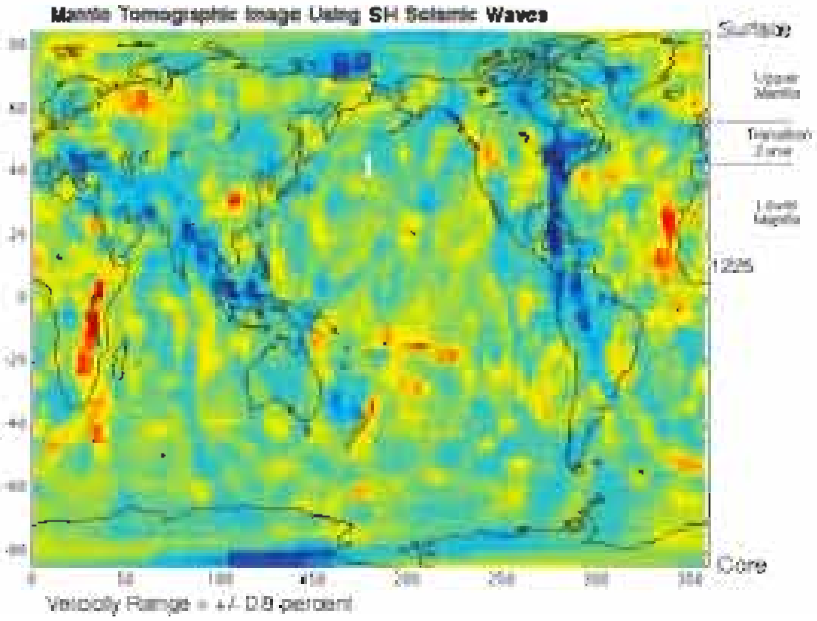


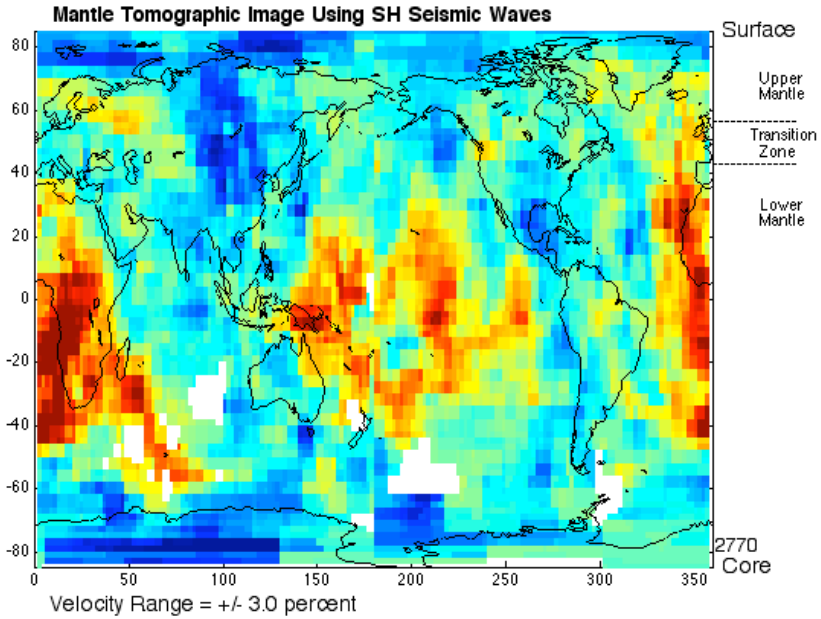
Red == hot (slow)
Blue == cold(fast)


Mantle Tomographic Image Using SH Seismic Waves
Surface
Upper Mantle
Transition Zone
Lower Mantle
Core
Velocity Range = +/- 8.0 percent


Mantle Tomographic Image Using SH Seismic Waves
Surface
Upper Mantle
Transition Zone
Lower Mantle
Core
Velocity Range = +/- 5.0 percent

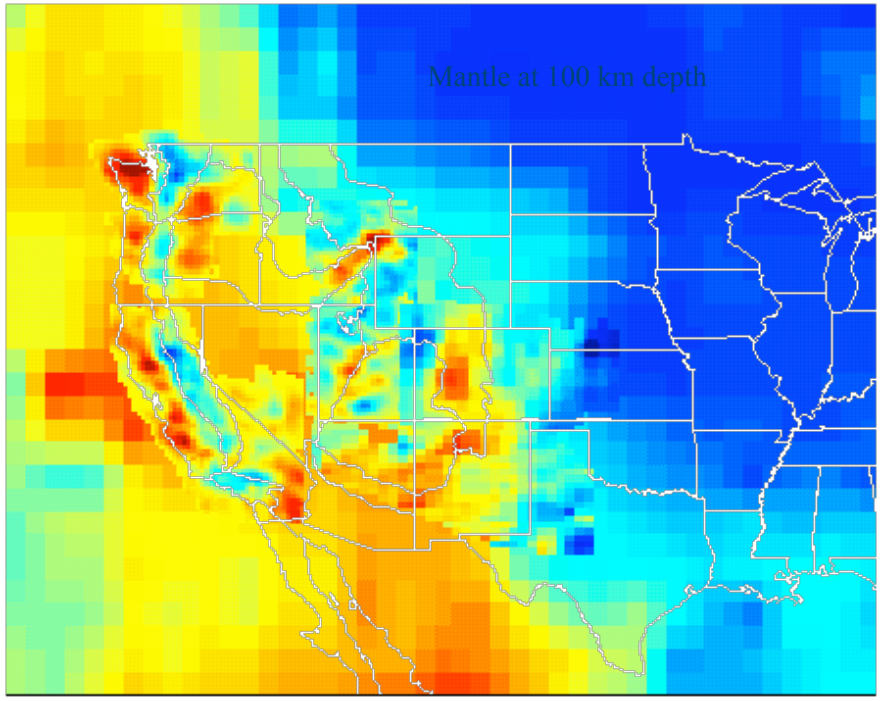

Mantle Tomographic Image Using SH Seismic Waves
Surface
Upper Mantle
Transition Zone
Lower Mantle
Core
Velocity Range = +/- 1.5 percent


Mantle Tomographic Image Using SH Seismic Waves
Surface
Upper Mantle
Transition Zone
Lower Mantle
Core
Velocity Range = +/- 0.8 percent



Seismic Waves and Heat

- "slow" regions may be the hot source rocks of mantle plumes.
- Near active volcanoes, seismologists have interpreted travel-time discrepancies to reconstruct the location of hot and partially molten rock that supplies lava for eruptions.



Earthquakes and Geochemical Cycles

- Water released from the slab enhances brittle fracture in the slab,
  - water is necessary for deep earthquakes in the Benioff zone