UNIVERSITY OF OSLO

GEO-DEEP 9300: Introduction to body wave tomography

Valerie Maupin

Mantle cartoon

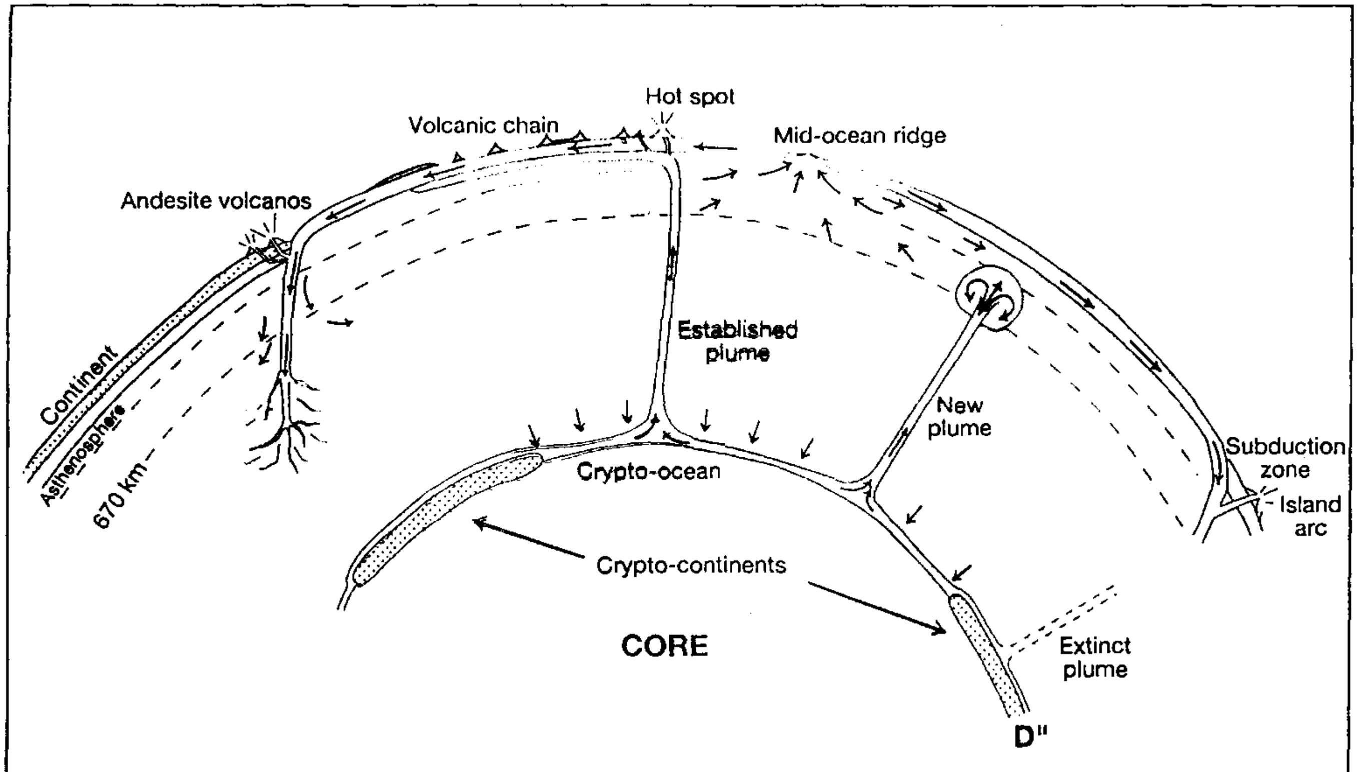


Figure 6.5. A pictorial representation of mantle convective processes. Stacey, 92.

Where does this come from?

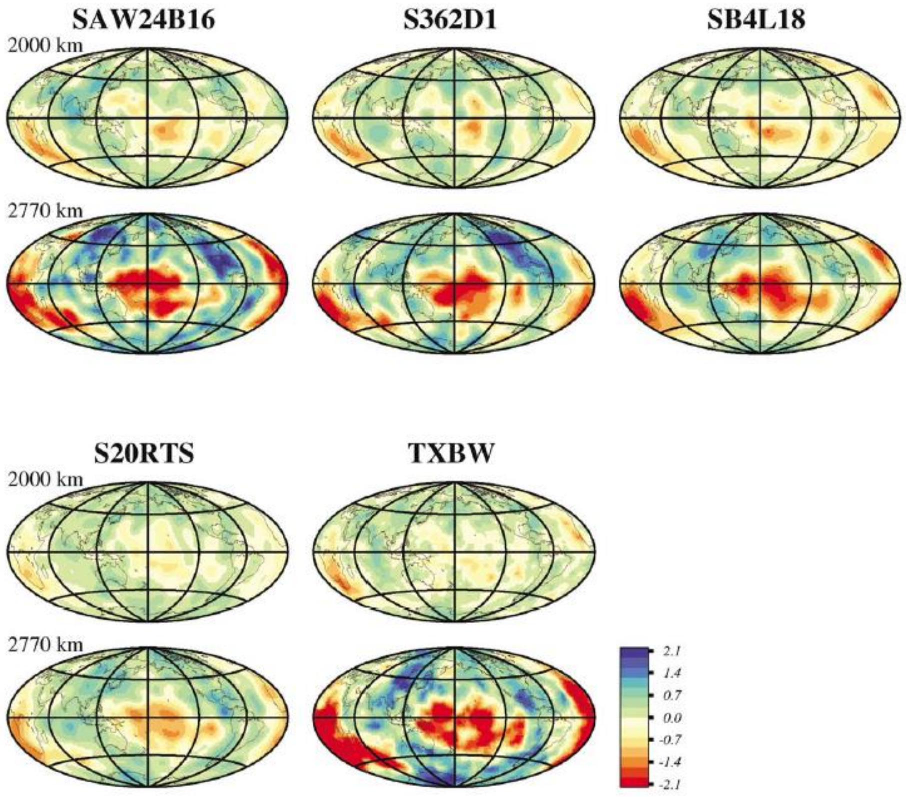


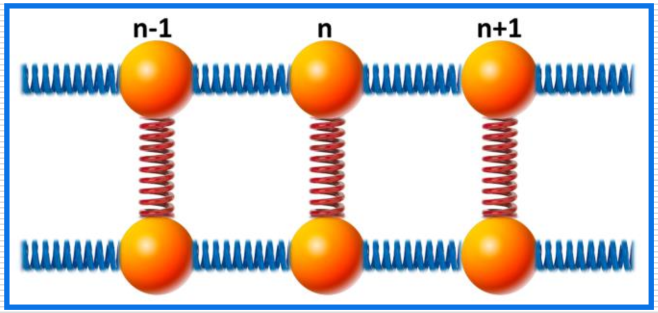
Fig. 4. Comparison of maps of S velocity heterogeneity at 2000-km and 2770-km depths for the same models as those considered in Fig. 1 (the scale is in % relative to the average velocity at each depth). Note the change in the character of heterogeneity in the vicinity of the CMB: amplitudes increase significantly, and the distribution is shifted to longer wavelengths. The two major low velocity regions ('superplumes') visible at 2770-km depth in the central Pacific and under Africa continue upward in most models, but the core of the anomaly becomes much narrower, as can be seen at 2000-km depth in the three top models.

after Romanowicz, 2003

Velocity of seismic waves

The velocity of the wave is related to the forces connecting atoms in the material.

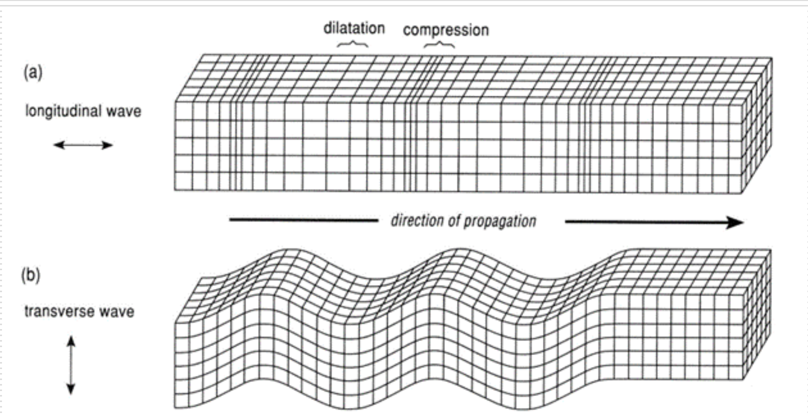
Vary with:
- Composition
- Structure
- Temperature
- Pressure
- etc

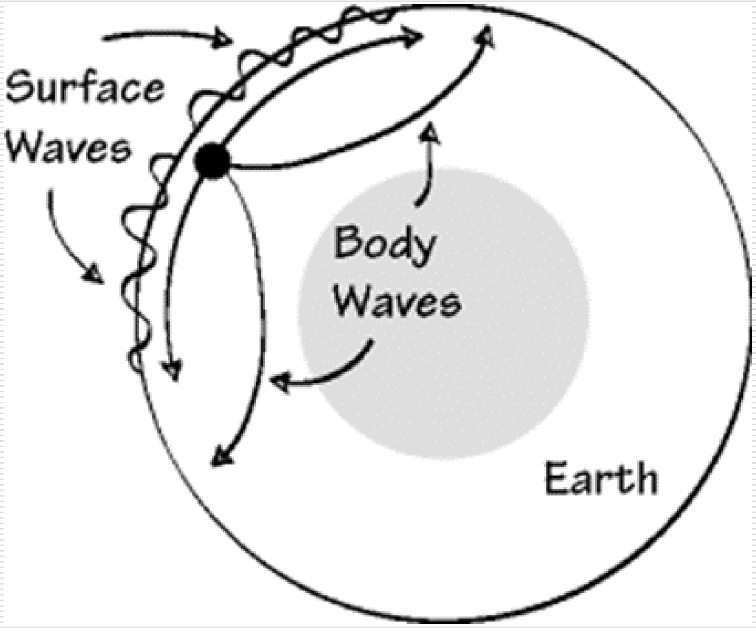


Hard (cold) material: high velocities;
Soft (warm) materials: low velocities

Body wave and surface wave tomography

P and S waves





Seismological data to probe the mantle

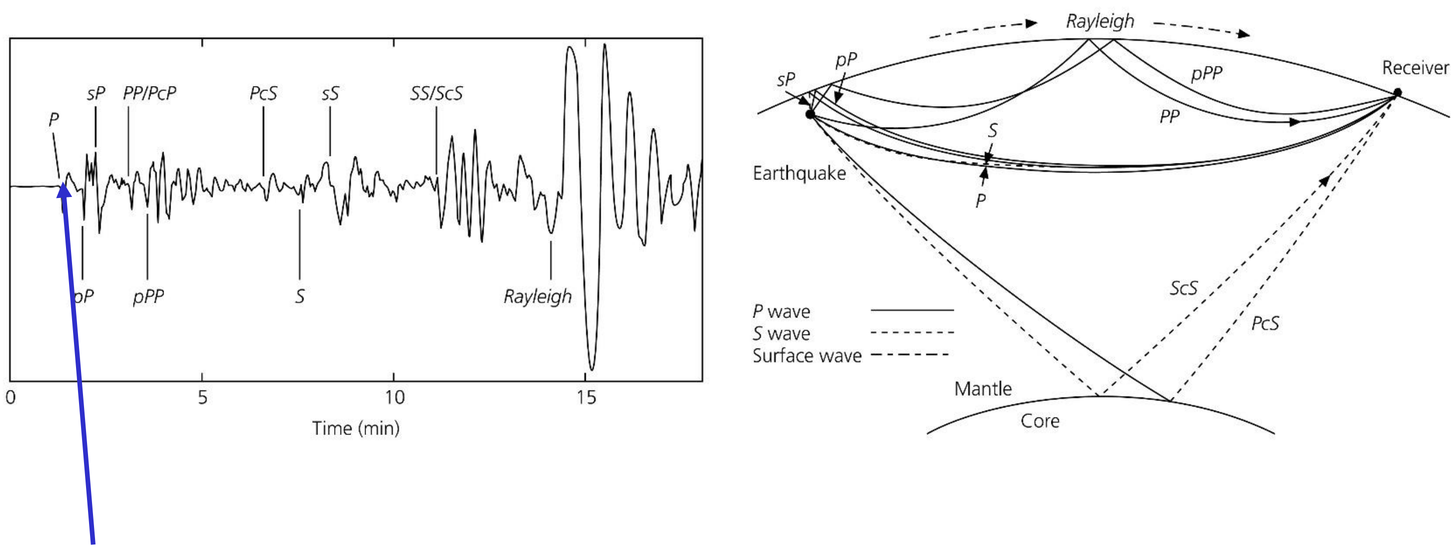
- Body wave tomography: Analysis of P and S waves arrival times

- Surface wave tomography: analysis of surface wave velocities and of the eignefunctions

- Waveforms in general
- Converted and reflected waves: receiver functions
- Differential times between S waves on different components: anisotropy

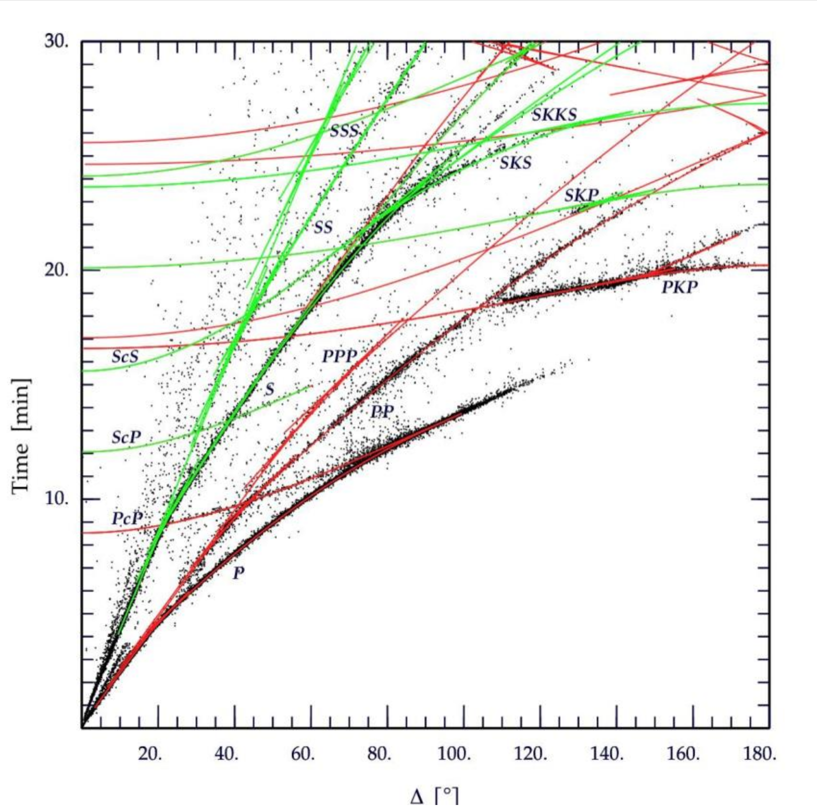
Arrivals and paths

Figure 1.1-3: Example of seismogram, showing accompanying ray paths.

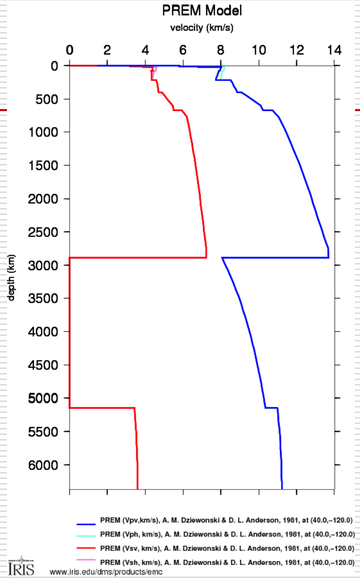


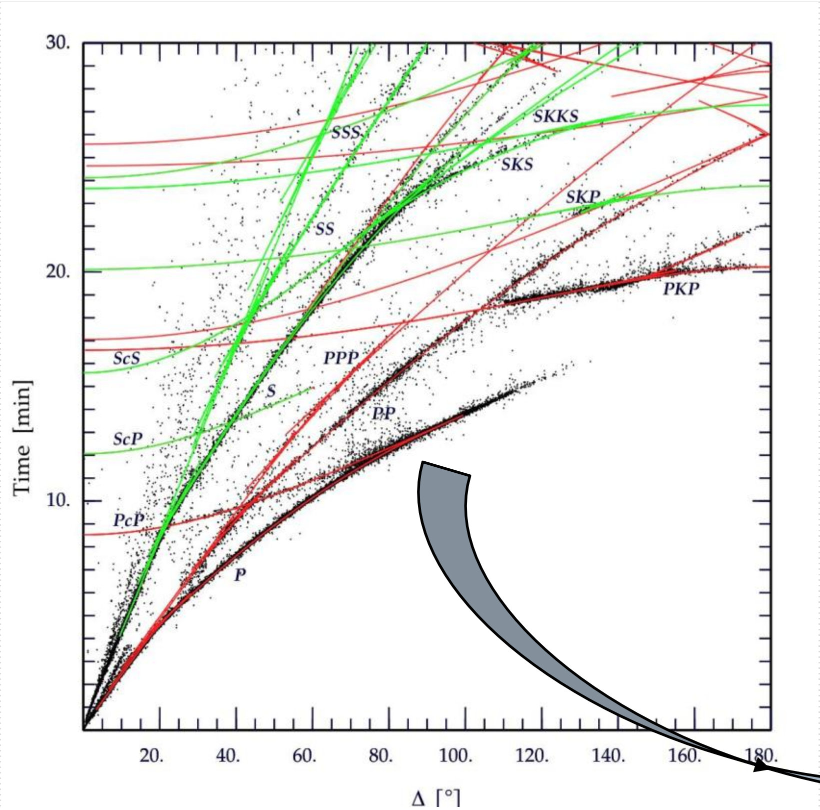
"pick" the arrival time

Arrival times at different distances from the earthquake



P wave paths in the mantle and the core





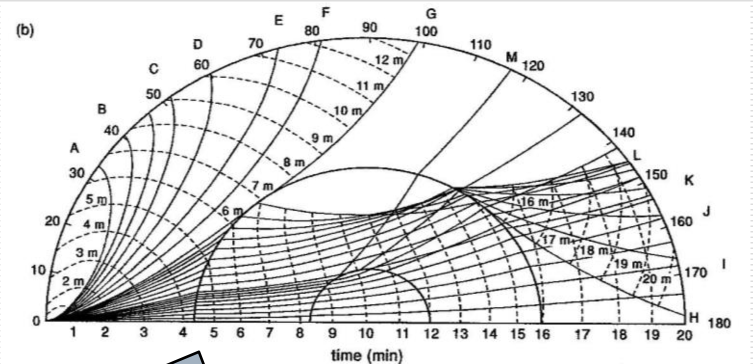
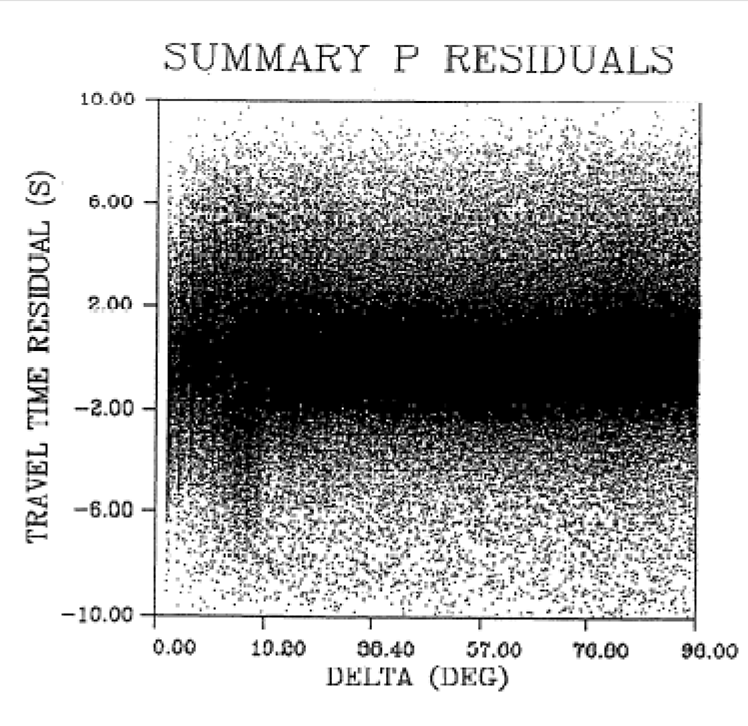


Figure 4.20 Ray ... ne Earth.

Amplitude of the traveltime residuals



Compare to traveltime of 600s for a P wave at 60deg distance

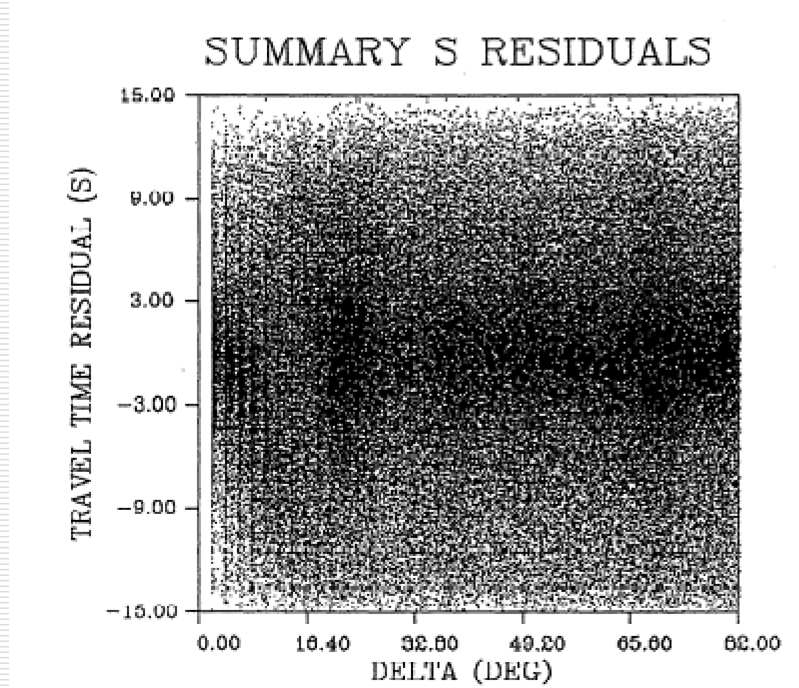
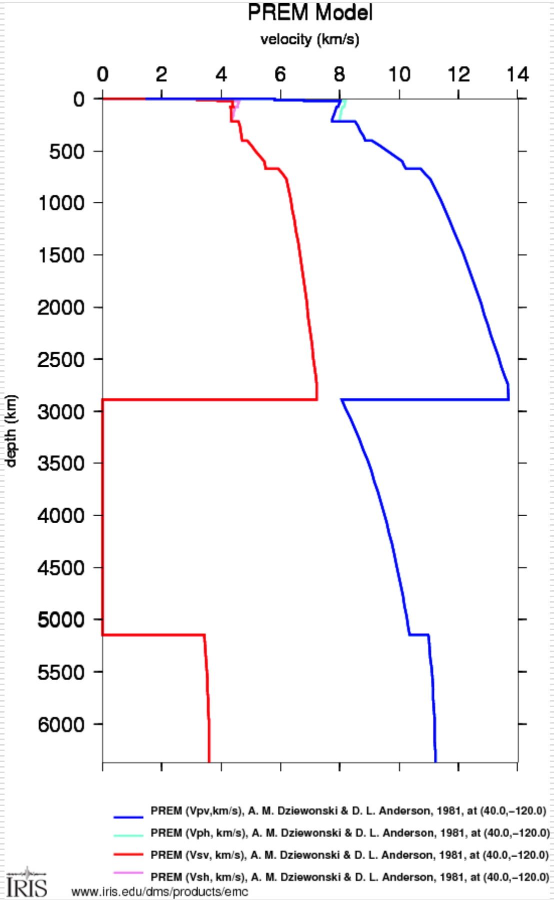
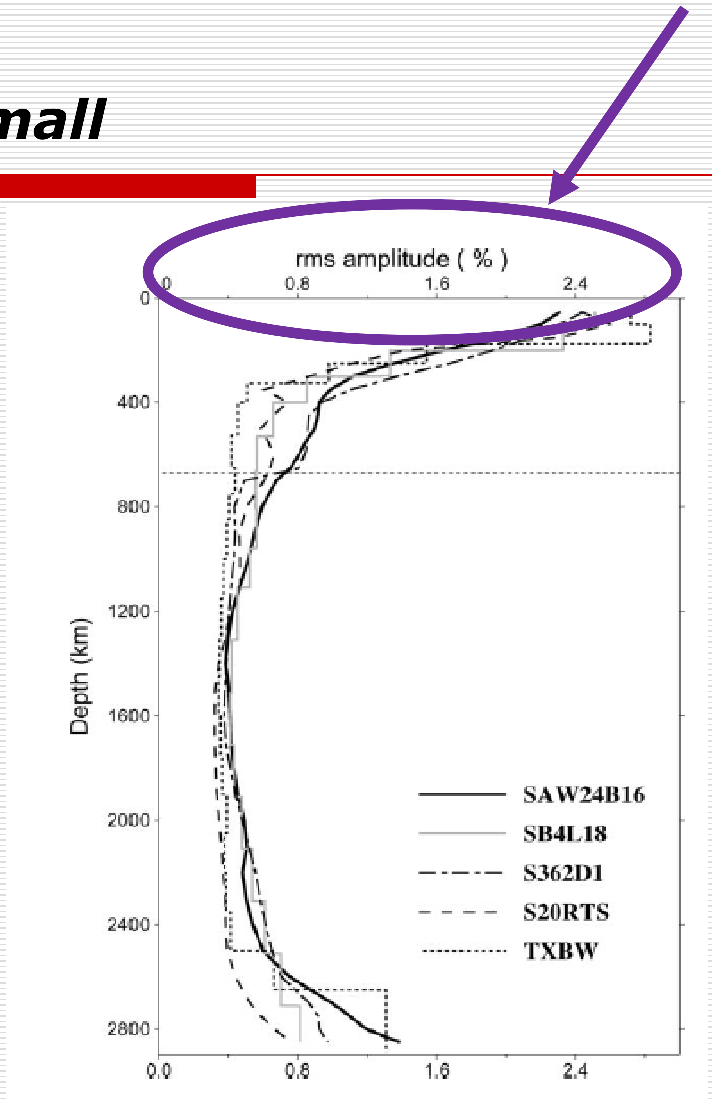


Figure 2. Distribution of *P* and *S* summary ray travel time residuals computed using a background velocity model of IASP91.

Vasco et al. 1994

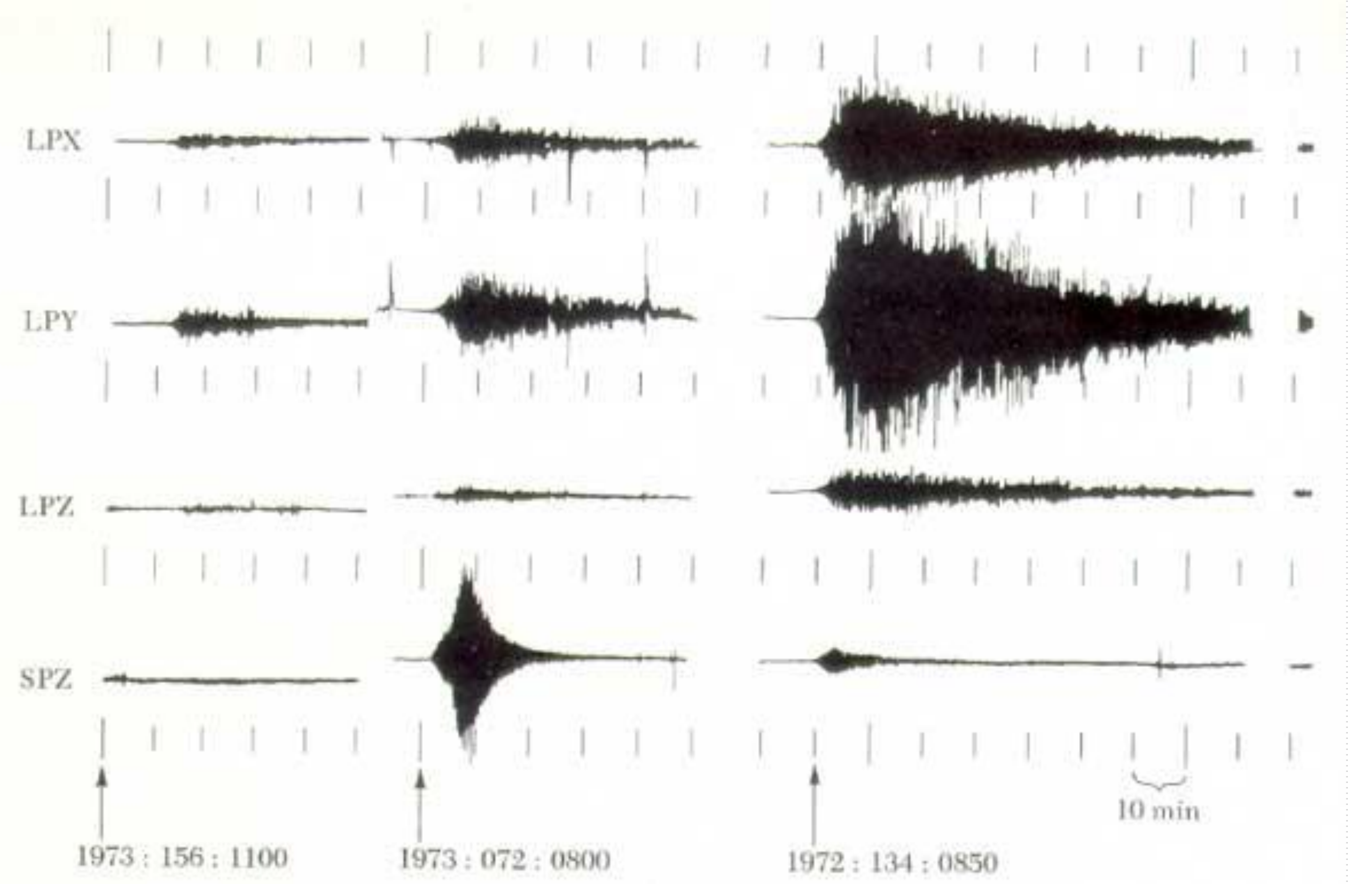
Lateral variations are small



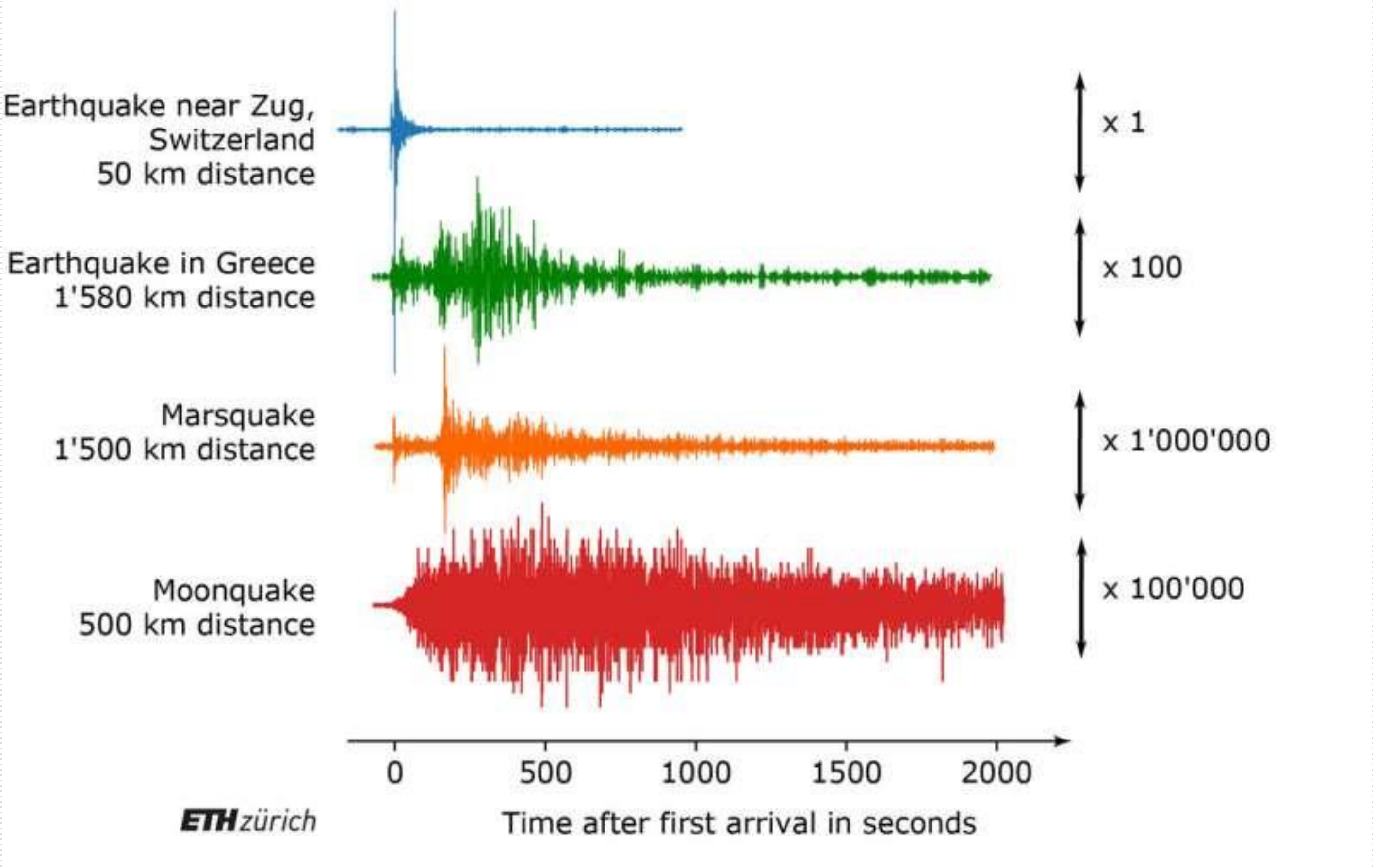


after Romanowicz, 2003

Moonquake recording

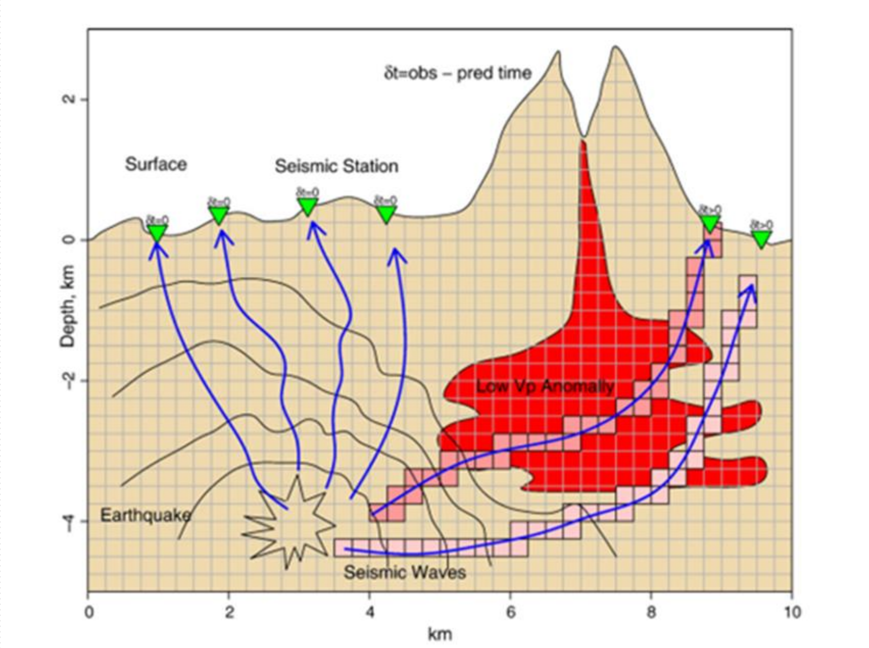


Deep and shallow moonquake and meteoroide impact recording on the Moon (from NASA).


Earthquake near Zug,
Switzerland
50 km distance
Earthquake in Greece
1'580 km distance
Marsquake
1'500 km distance
Moonquake
500 km distance
x 1
x 100
x 1'000'000
x 100'000
0
500
1000
1500
2000
Time after first arrival in seconds
ETH zürich

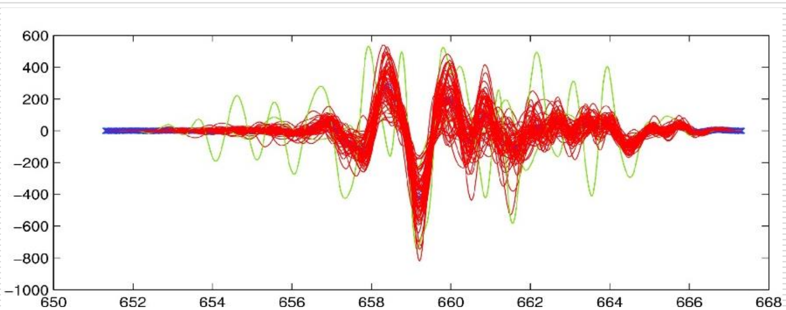
Principle of tomography

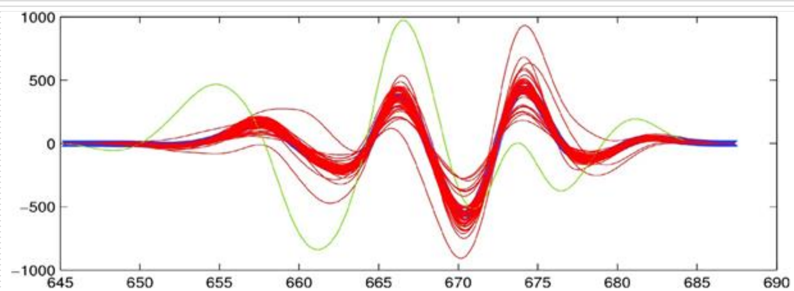
$$t = t_0 + \int_{path} \frac{1}{v(\vec{x})} ds$$

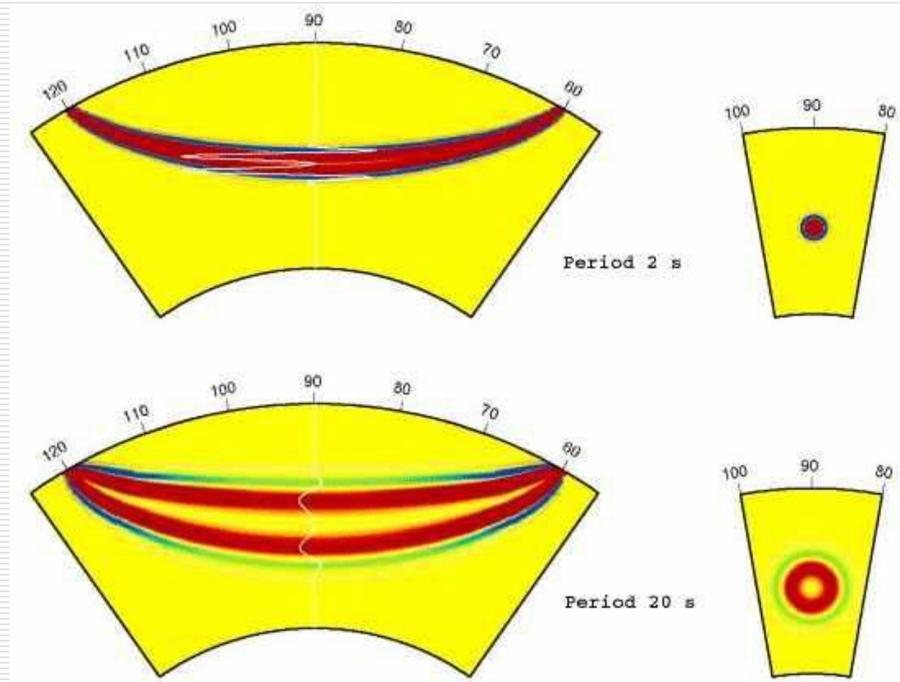


- All the waves which travel through the slow region will arrive **late.**
- The amount of delay on each ray depends on the strength of the heterogeneiety and its size.

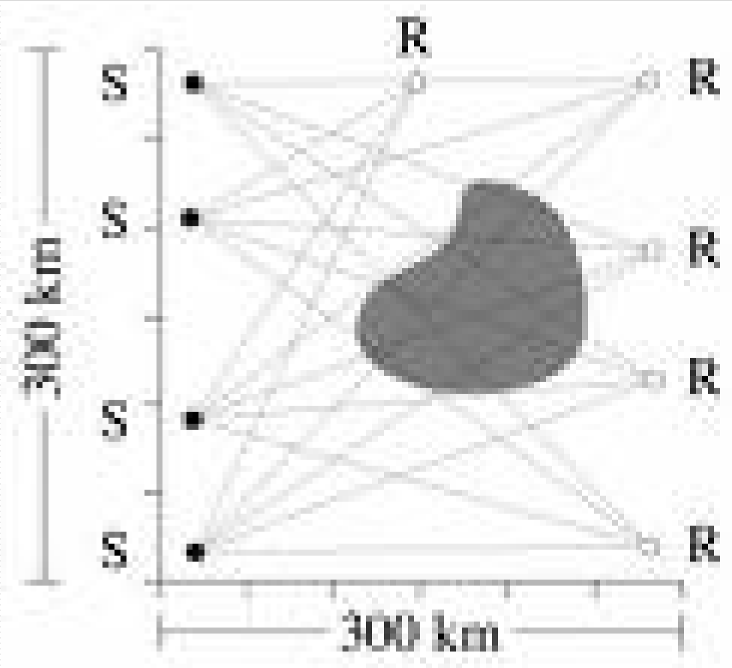
Sensitivity of the traveltime to the velocity in the model





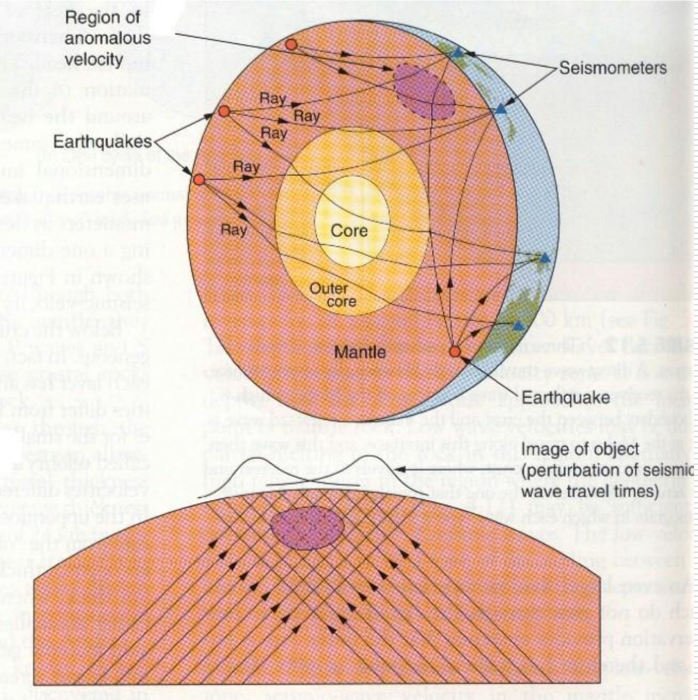


Principle of tomography



Using rays which criss-cross the region, one can map in 3-D the areas with low or high velocities.

Principle of regional body wave tomography



- Body waves
- Traveltimes
- Regional network of stations
- Earthquake distribution
- S and/or P waves

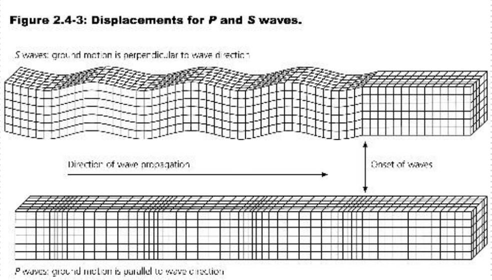
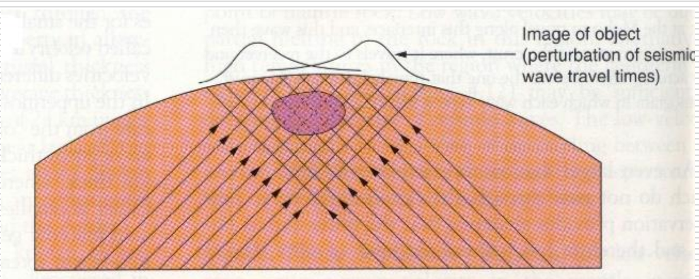
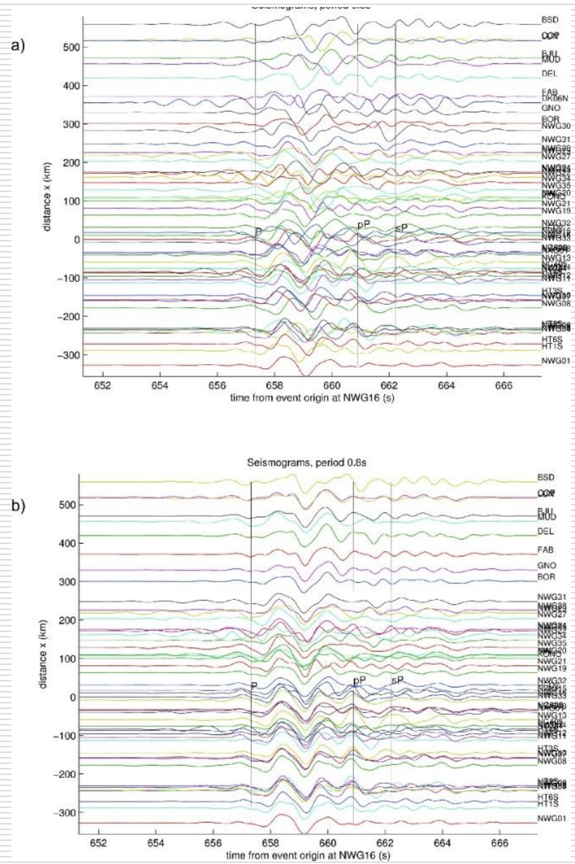


Figure 2.4-3: Displacements for *P* and *S* waves.

Principle of regional body wave tomography

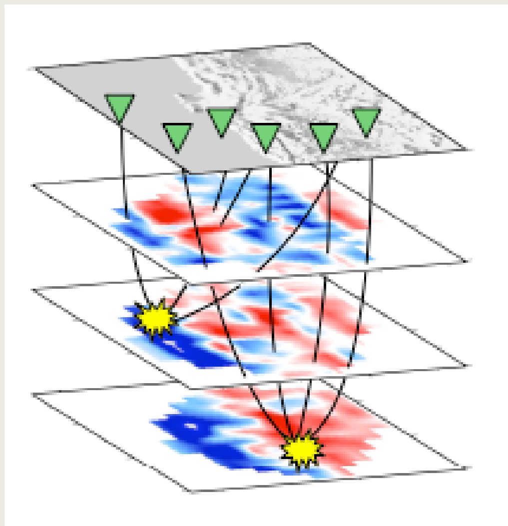
Delays between stations,
not absolute travel times





Gives models of the upper mantle

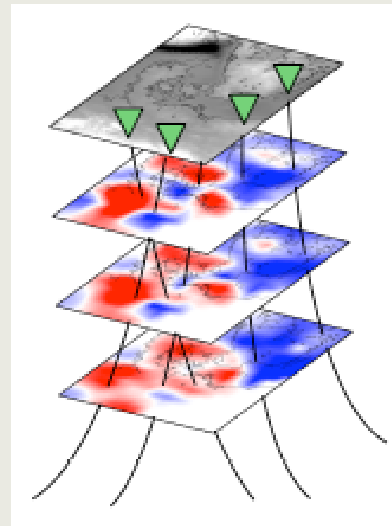
Local Earthquake Tomography



source and receiver with in the study volume

crustal studies

Teleseismic Tomography

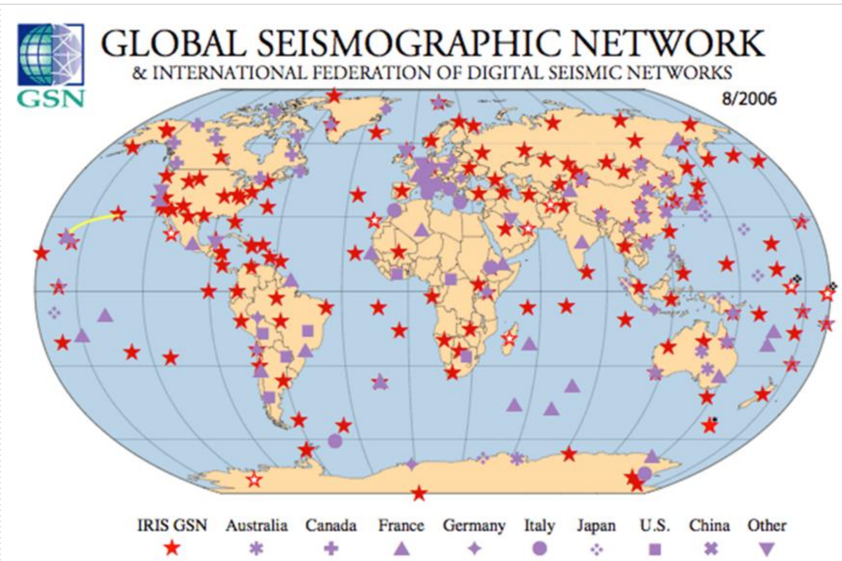


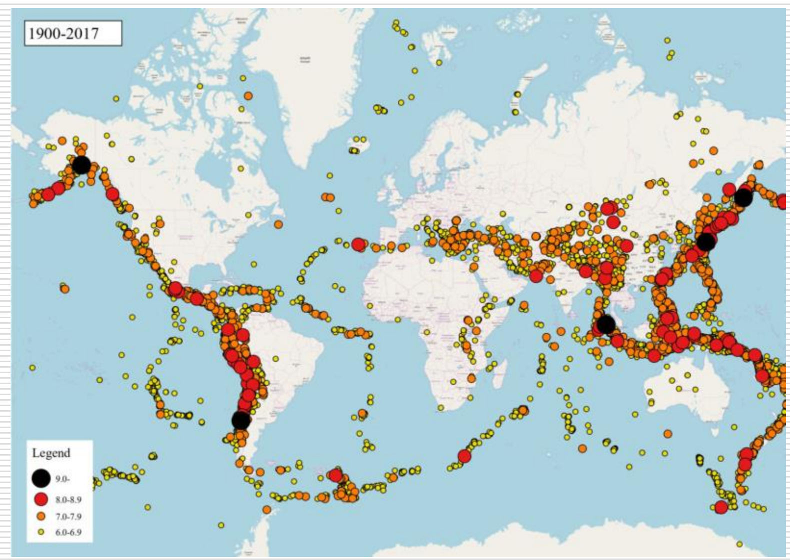
sources are outside study volume

mantle studies

ISC database: for global models

- About 2500 stations report to the ISC (International Seismological Centre): thousands of earthquakes/year, millions of traveltimes.
- Primary objective: earthquake location and catalogue
- Spin-off: global arrival time database





Traveltimes, origin times and locations

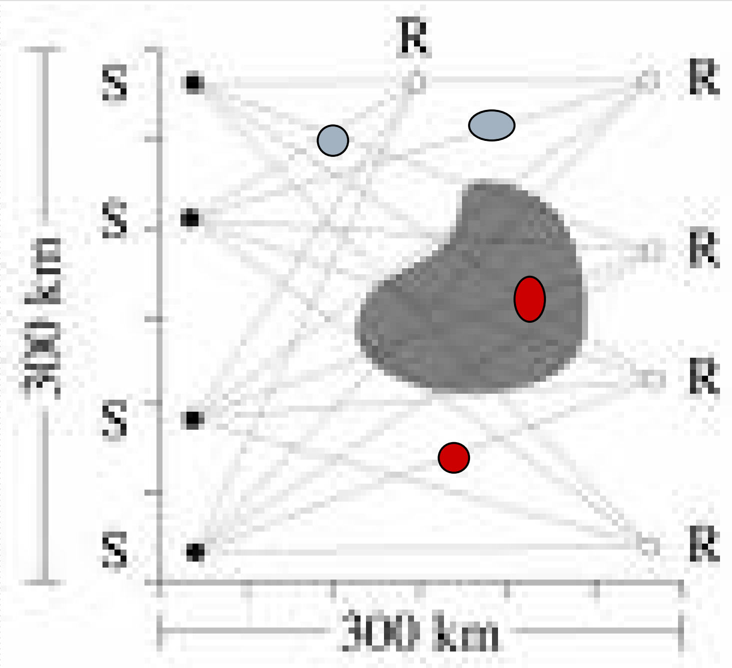
The arrival time at a station depends on:

- Origin time of earthquake
- Epicenter of earthquake
- Depth of earthquake
- Path and velocity along the path

In addition, errors due to

- Clock problems
- Reading errors
- Localized strong heterogeneities in the crust below the station

The effect of errors in the data



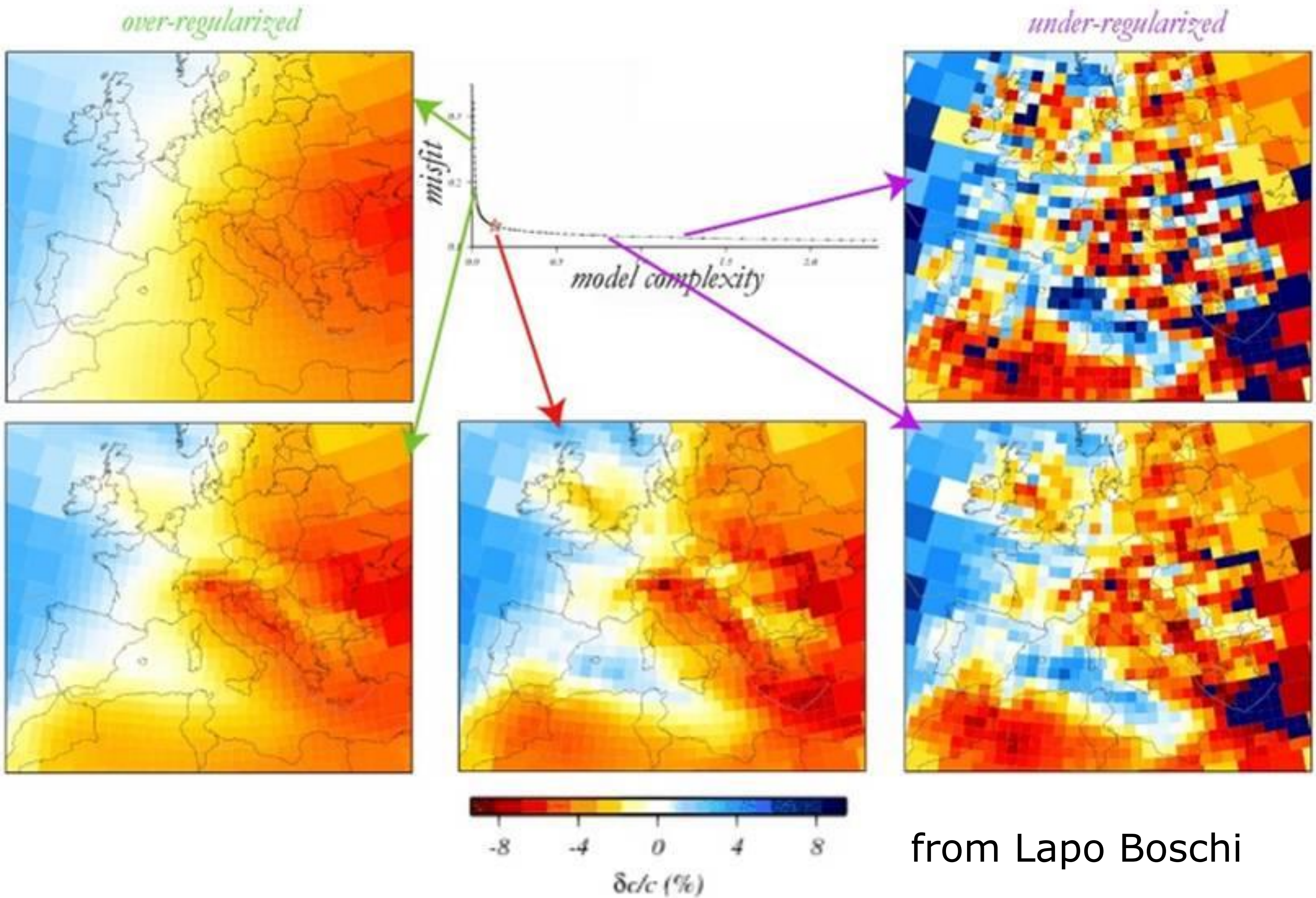
Small errors in the data can be mapped as small-scale heterogeneities.

What to keep?

Not a simple question:

Necessity of regularization (also called damping)

Tomography results are non-unique



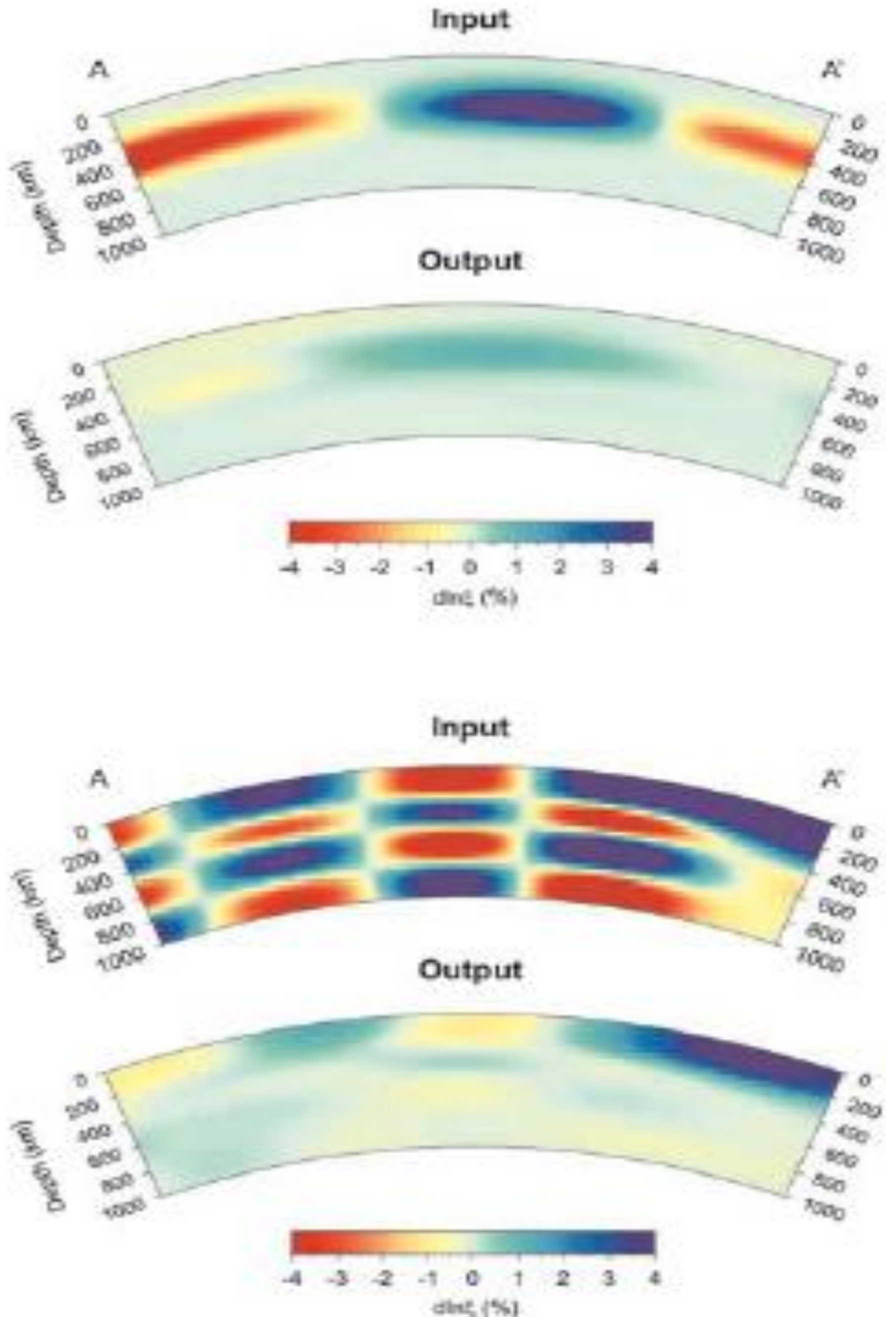
from Lapo Boschi

Effect of damping

- Small-scale heterogeneities: might not be seen
- Amplitude of the large-scale heterogeneities: might be underestimated
- Basically the resolution is changed: need for a resolution text

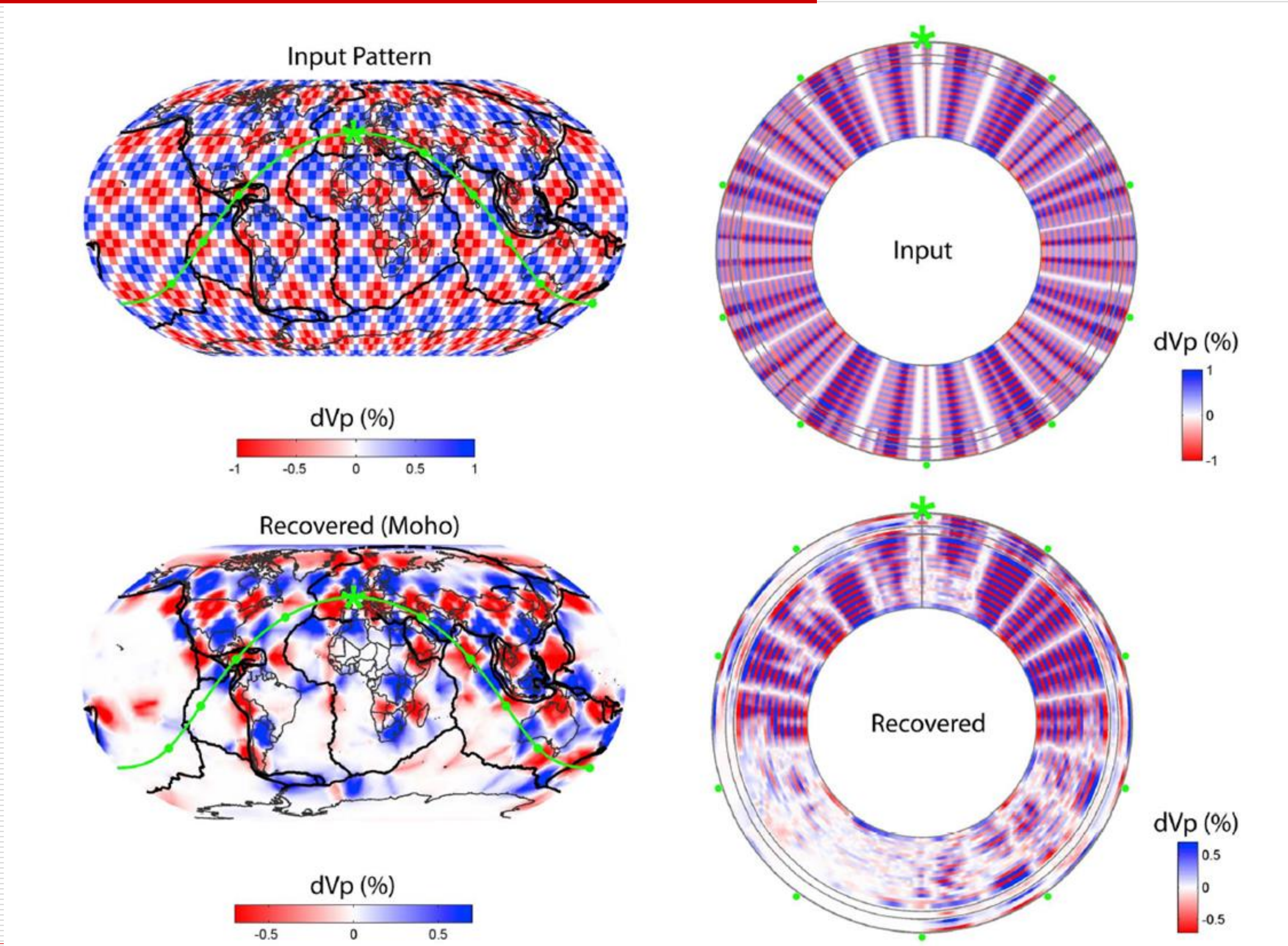
Resolution test

- Prepare a model (input)
- Compute synthetic data in model
- Add realistic noise
- Invert synthetic data with same parameters as real data
- Compare input and inverted models



Marone et al, 2007

Better resolution in the northern hemisphere



Simmons et al. (2012)

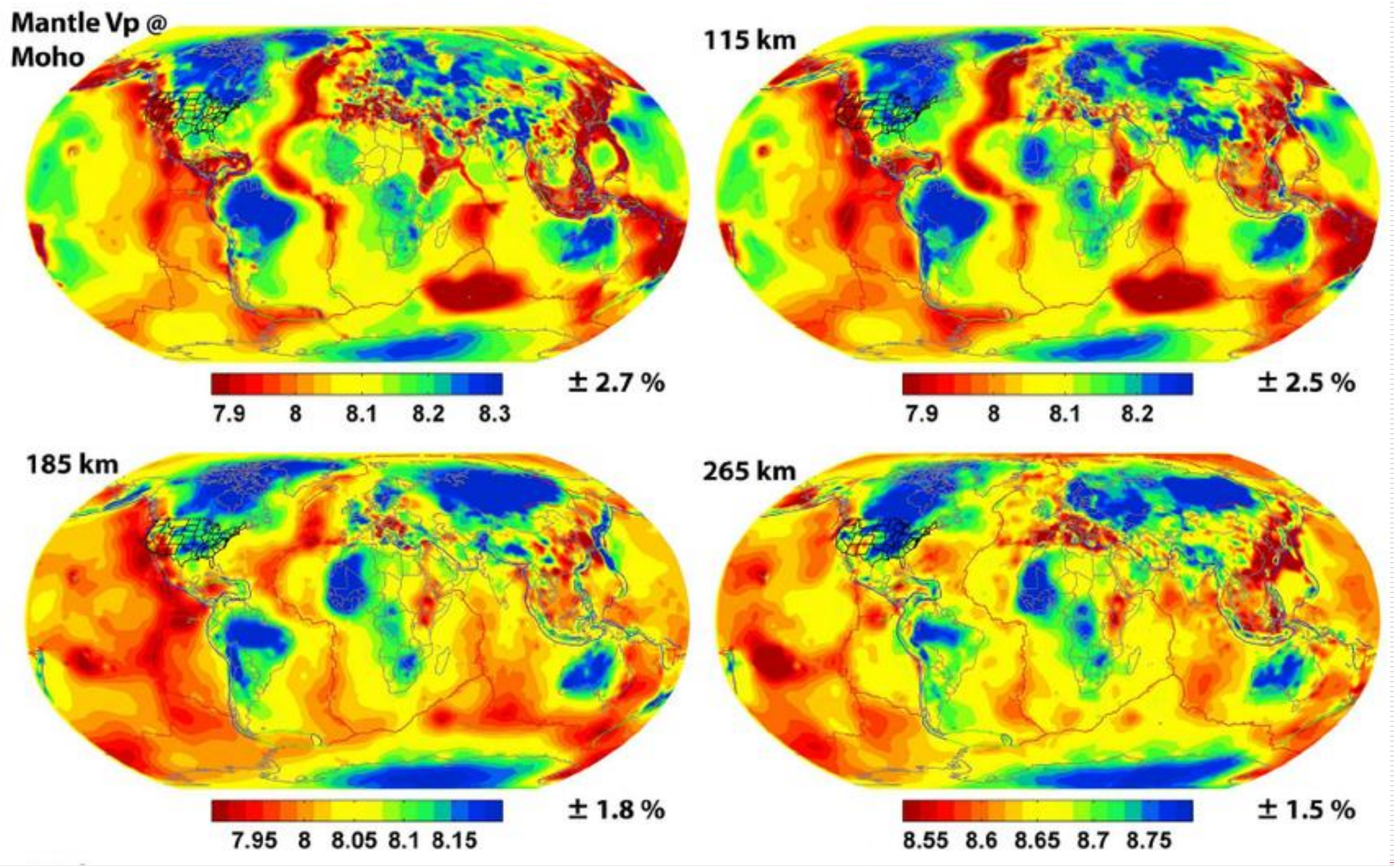
Advantages of body-wave tomography

- Maps deep into the whole mantle and core
- Give information on P- and S-wave velocity
- Global models give information on the absolute values of the velocities

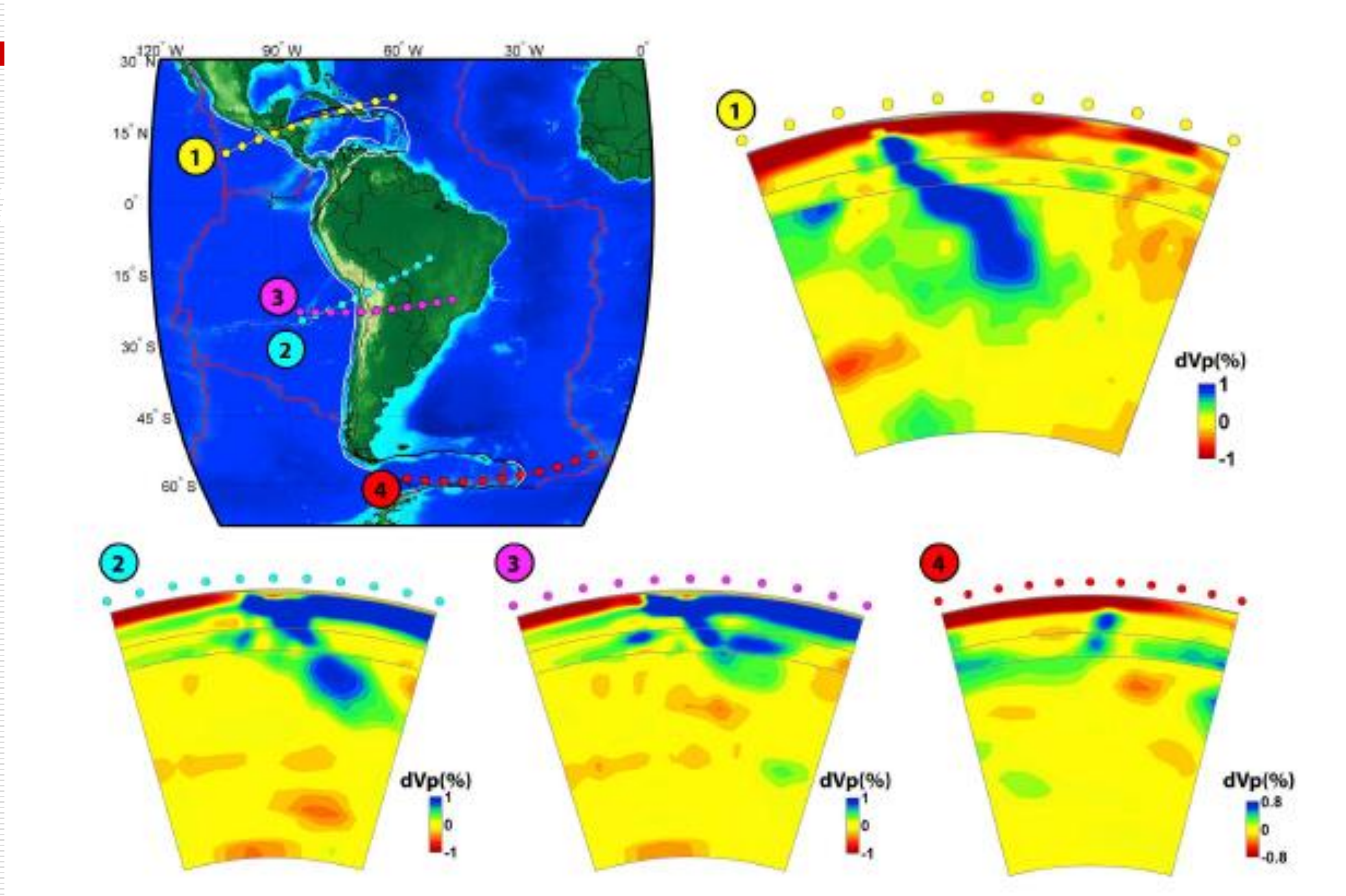
Disadvantages

- Uneven global coverage (North/South)
- Not so-well suited for the oceanic lithosphere due to lack of earthquakes and seismometers
- Most regional bode-wave tomography provide only relative velocities → more difficult to interpret

A model of P-wave velocity in the lithosphere and asthenosphere



Simmons et al. (2012)

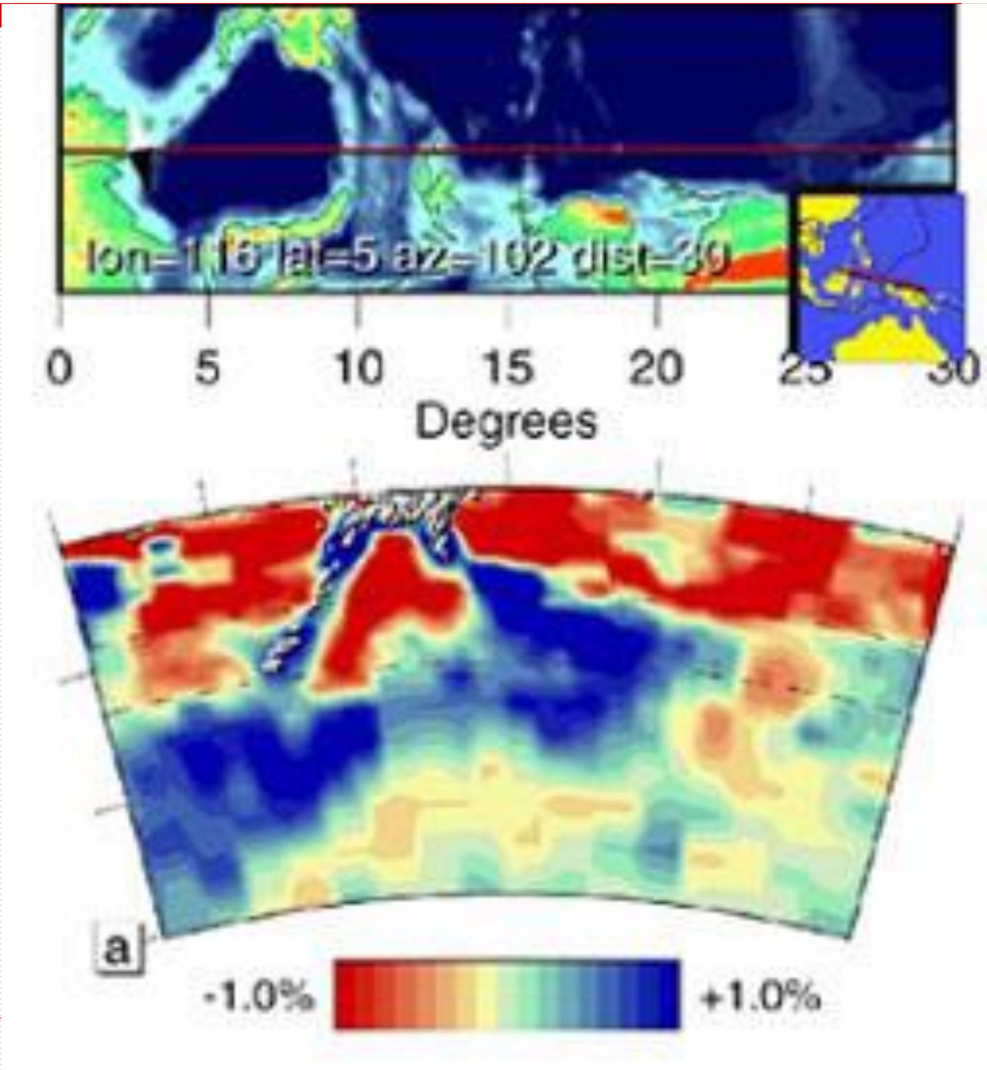


Simmons et al. 2012

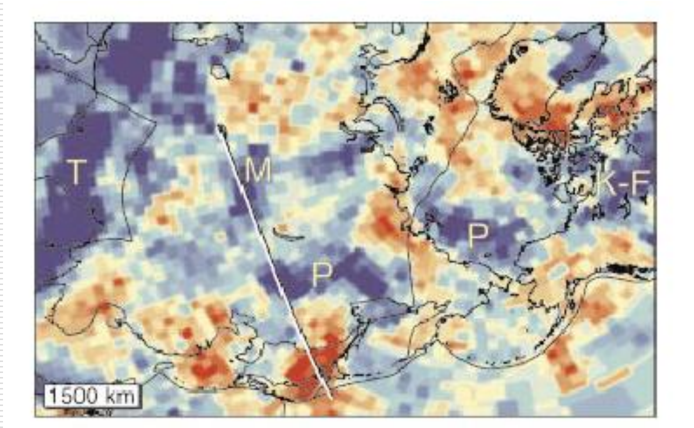
P-wave tomography (Spakman, vd Hilst)

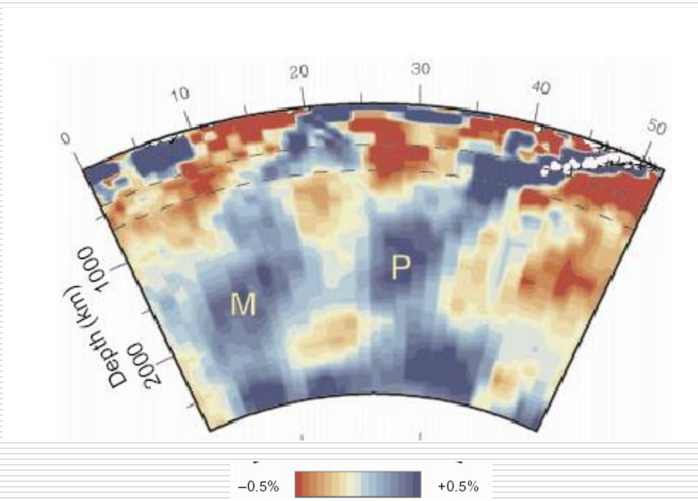
After cleaning
the database
and relocation of
the earthquakes:

Mapping of
P-wave velocity



P-wave tomography





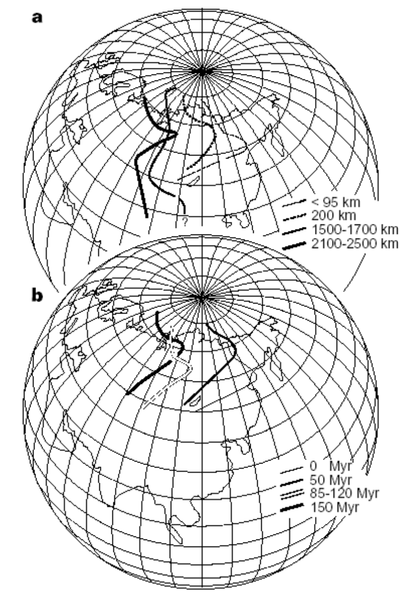


Figure 4 A comparison of the locations of tomographic velocity anomalies and the expected palaeolocations of the Siberian active margins. **a**, Locations of the lithospheric suture and the main axis of the ocean-lithospheric slab remnants as a function of depth, as determined from our tomographic results. **b**, Present-day and palaeogeographically reconstructed locations of the Mongol-Okhotsk-Verkhoyansk suture zones as a function of time (longitudes are arbitrary), using the palaeomagnetic pole determinations for Siberia of Zhao *et al.*[29] (81° N, 158.6° E for 50 Myr; 73.8° N, 202.4° E for 85-120 Myr; 70.1° N, 184.3° E for 150 Myr).

Van der Voo et al., 1999

Summary

- A powerful tool to map the interior of the Earth
- Lateral variations are small (order of %)
- Needs large amounts of data
- Regularization makes the results non-unique
- Common interpretation in terms of temperature
- Image continental lithosphere/oceanic lithosphere/slabs