Global seismology: The velocity structure of the Earth

Reading:
Fowler p126-130, 326-331, 336-348

Seismic phases
Nomenclature

The various seismic ray paths within the earth are coded as follows:
- P = P-wave in the mantle
- S = S-wave in the mantle
- K = P-wave through the outer core
- I = P-wave through the inner core
- J = S-wave through the outer core
- k = reflection from the mantle—inner core boundary
- i = reflection from the outer core—inner core boundary
- f = P-wave reflected from the surface of the earth close to the earthquake focus
- s = S-wave reflected from the surface of the earth close to the earthquake focus

Fig. 4.15. Deep earthquakes generate surface-reflected arrivals, termed depth phases, with the upgoing ray from the source labeled with a lowercase p or s. Ray paths plotted here are for an earthquake at 650 km depth, using the PREM velocity model.

Fig. 4.14. Global seismic ray paths and phase names, computed for the PREM velocity model. P-waves are shown as solid lines, S-waves as wiggly lines. The different shades indicate the inner core, the outer core, and the mantle.
Waves through the Earth

P-waves

S-waves

Arrival times

Seismic phases

Fig. 4.16. The vertical, radial, and transverse components of ground motion (velocity) from the January 17, 1994 Northridge earthquake recorded at the IRIS/IDA station OBS at 88.5° range. The original broadband records have been filtered to between 15 and 100 s period. Time is in minutes relative to the earthquake origin time; amplitudes are self-scaled.
Seismic phases

Short period arrival times

Fig. 13. A stack of deep-earth (-C (vertical)) component data from the global seismology network (NSNW, 1990). Solid lines are for key to the phase names. (From Sato et al., 1990).

Seismic phases

All arrival times

EXPLORING THE EARTH THROUGH SEISMOLOGY
1D velocity model for the Earth

Using the arrival times of all these phases at stations around the globe we can calculate a 1D average velocity model for the Earth.

- Uppermost mantle low-velocity zone
- Transition zone: 410-660 km
  - Earthquakes stop at ~660 km
- Lower mantle
- Core-mantle boundary
- Outer core: must be fluid as $V_S = 0$
  - Also required for Earth’s magnetic field
- Inner core solid

**Velocity and mineralogy**

Figure 3.2: The structure of the outermost 700 km of the Earth, showing the variation of Swave velocity ($V_S$) with depth. Stippled bands represent major velocity changes associated with high-pressure phase transitions.
3D velocity variations?

Features we expect will cause 3D velocity anomalies:

• Hot, upwelling molten rock at mid-ocean ridges
• Old, cold subducting lithosphere
• Hot, upwelling mantle plumes
**Imaging 3D velocity variations**

**Tomography**

Use the variations in traveltimes of seismic arrivals to determine regions of high and low velocity.

![Diagram showing raypaths and velocity variations](image)

**Borehole tomography**

Tomography result: velocity variations between the holes.

Low velocities due to a cavity.

![Diagram showing borehole tomography](image)
Whole Earth tomography

Use variations in the arrival times of seismic energy

If ray has passed through a high-velocity region then phase arrived early

If low velocity region phase arrived late

⇒ Use this information to reconstruct an image of the mantle

Subduction

Western pacific
### Subduction

**Western Pacific**

- **Japan trench**
- **Izu slab**
- **Kuril slab**
- **Farallon slab**

- Originates from a time when there was subduction all along the western US.
- We find evidence of this slab extending all the way to the core-mantle boundary.

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**Farallon slab**

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Mid-ocean ridges

EPS 122: Lecture 13 - The velocity structure of the Earth
Hotspots and mantle plumes

*Strings of volcanic ocean islands recording the motion of the plate*

Hawaiian chain

The formation process

Iceland

*The plume beneath the Iceland hotspot*
Iceland

Azores
Canary
Cape Verde

Montelli et al.
Hawaii plume?

African cratons

The difference between oceanic and continental crust
Velocity and mineralogy

Figure 3.2. The structure of the outermost 1000 km of the Earth, showing the variation of S-wave velocity (kms$^{-1}$) with depth. Stippled bands represent major velocity changes associated with high-pressure phase transitions.

Figure 10-2. Phase diagram of aluminum-bearing minerals with melting intervals (gray), sub-solidus reactions, and geothermal gradients. After Wyllie, P. J. (1981). Geol. Rundsch. 70, 128-163.