Chapter 10: Earthquakes and Earth's Interior

The interior structure of the Earth and its composition must be inferred from indirect observations. For example, the average density of the planet, comparisons with the composition of meteorites, and the presence of the Earth's magnetic field all provide clues as to the composition of Earth. Seismic data provide the most compelling evidence for the internal structure of the Earth. We will therefore focus much of our discussion on the seismic observations that lead to inferences about overall Earth structure.

Observations relevant to the composition and structure of Earth

Seismic waves
- Body waves (P and S waves)
- Surface waves

Paths of seismic energy through the Earth
- refracted and reflected waves

Determining the location of an earthquake

Estimates of earthquake magnitude and frequency

Global distribution of earthquakes
- Where do most earthquakes occur?
- Benioff zone as a manifestation of subducting plates

Seismic structure of the Earth
- Moho - discontinuity between crust and mantle
- Shadow zones and evidence for a liquid outer core and solid inner core
- The low velocity zone (asthenosphere)
- Structural transformations and the 400 km and 670 km seismic discontinuities

Evaluating earthquake risk
- Elastic rebound theory
- Measures of strain accumulation
- Earthquake hazards in the U.S.

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First 20 minutes needed to finish up rock deformation (transform faults, folds, law of Vs)

How do we learn about the Earth's Interior?

1) Seismic energy (much more about this later)
velocities and densities (from lab calibrations)
densities above CMB consistent with Mg silicates
densities below CMB consistent with metallic Fe

2) Mass of the planet
how to determine the mass of Earth?
Kepler (17th century)

$$\text{period (T)} = G \times (r^3/\text{mass}_{host})^{1/2}$$

where r = orbital radius. All objects orbiting at same radius have same period (otherwise bad news for astronauts on space walks). From orbital period of moon we can estimate the mass of earth.

3) Average density of earth
provides information on chemistry
atoms have narrow range of sizes (1-4 angstroms) but widely varying mass
ave density of earth (corrected for P effect) is 4.3

4) Compositional clues from meteorites
wide range of combinations of elements that could give 4.3 ave density
carbonaceous chondrites (preserve low T volatiles)
compare with solar composition (spectra) shows ~1:1 with carbonaceous chondrites
Mg,Si,Fe 91% of metals
Al,Ca,Ni,Na poor second

5) Direct samples of upper mantle (xenoliths) - comps similar to basaltic achondrites

6) Magnetic field
motion of molten Fe (conductor)
alternative: permanent magnet not plausible (>Tc and wouldn't give reversals)

7) Heat flow
sources of heat
kinetic energy
radioactive decay
latent heat xtl of IC

conduction - transfer of vibrational energy convection

seafloor spreading/plate tectonics direct evidence of convection

Types of seismic waves

Body waves - analogous to sound waves, propagate in 3D from source

P waves (primary)

energy propagates by change in volume (compression/dilation)

typical speeds:

continental crust = 6 km/sec

upper mantle = 8 km/sec

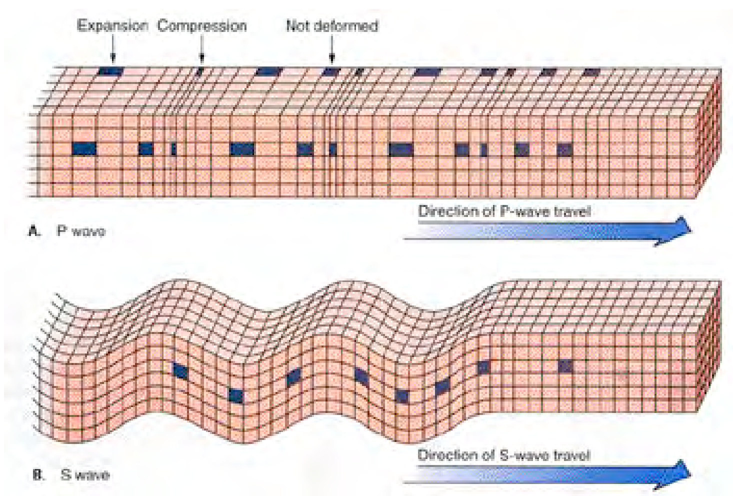
S waves (secondary)

energy propages by change in shape (NB: not possible in fluids)

typical speeds:

continental crust = 3.5 km/sec

upper mantle = 5 km/sec



Surface waves - analogous to ocean waves, propagate in 2D along interface

typically the largest signal on seismogram

dispersion according to wavelength (longer wavelengths travel deeper, faster)

Seismic paths through interior of earth

As with sound waves, seismic energy can be reflected or refracted at boundaries.

Reflection

above critical incidence angle, energy is reflected (at angle = incidence)

degree of reflectivity depends on impedance contrast

Refraction

Snell's law

$\sin A_1/V_1 = \sin A_2/V_2$

because velocities in earth generally increase with depth, upward curved paths

Even with homogeneous earth, P effect would lead to curved paths. As we'll see below, layered structure of earth (with generally higher velocities with depth) results in even more pronounced curvature.