Lecture 15: Seismology and the Earth's Interior Oct. 27, 2006

Goals for this lecture:
1) How to locate EQ
2) EQ magnitudes
3) Global distribution of EQ
4) Seismic structure of the earth
5) Elastic rebound theory
6) EQ hazards

Determining earthquake location

Some terminology
- *focus* - center of energy release
- *epicenter* - point on the surface above the focus

Recall arrivals on seismogram (P,S,surface)

Why use P-S times?
- taking this difference removes dependence on time of event
- P-S interval grows to about 10 minutes for distance of 12000 km

Wrapping the triangulation technique around the globe
- distance traveled on curved path equivalent to (smaller radius) small circle

Earthquake magnitude and frequency

Richter scale
- determined from amplitude of motions on seismograph
  - calibrated as a function of distance to source
  - calibrated for rock type near receiver
- each unit change on the Richter scale represents ~30 fold increase in energy release

Moment
- based on the amount of energy released
- Mo = mu * A * D
  - where mu = rigidity (typically 3 x 10^{10} N/m^2)
  - A is area and D is displacement
  - so moment is in joules (Nm)
- M = (2/3)*log10(Mo) - 6.0

- e.g. 50 km x 15 km area, with 3 m of slip >> 7 x 10^{19} J =>> M = 7.2

Frequency vs magnitude
- as you might guess, large magnitude quakes are less frequent
- related by power law
  - ~10^6 M=3.4
  - 1/yr M>8.0

Global distribution of earthquakes

Where do earthquakes occur?

plate boundaries

specifically 80% in circum Pacific belt, 15% in Med-Himalayan belt

Benioff zone

most EQ are shallow than 100 km (<20 km in continental areas)

deepest earthquakes are ~700 km

cold slab descends into mantle =>> brittle behavior possible

pattern at subduction zones

Seismic structure of the earth

Much of our knowledge of the internal structure and layering in earth is derived from seismic observations. Indirectly contribute information about composition as well.

First order discontinuities

Moho

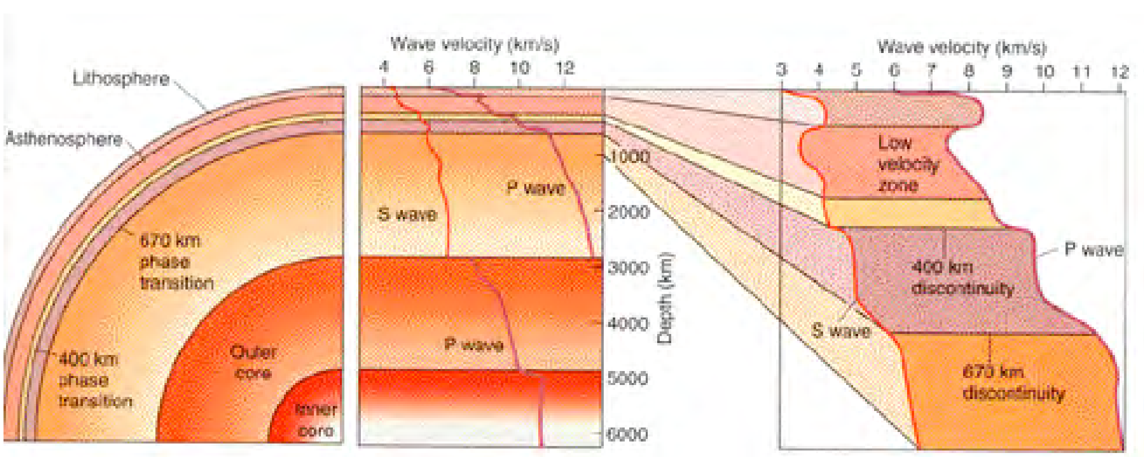
discovered by Mohorovicic, who noted two distinct sets of P and S arrivals

these duplicate arrivals imply seismic energy refracted in faster material

boundary between crustal material (P = 6-7 km/sec) and upper mantle (8)

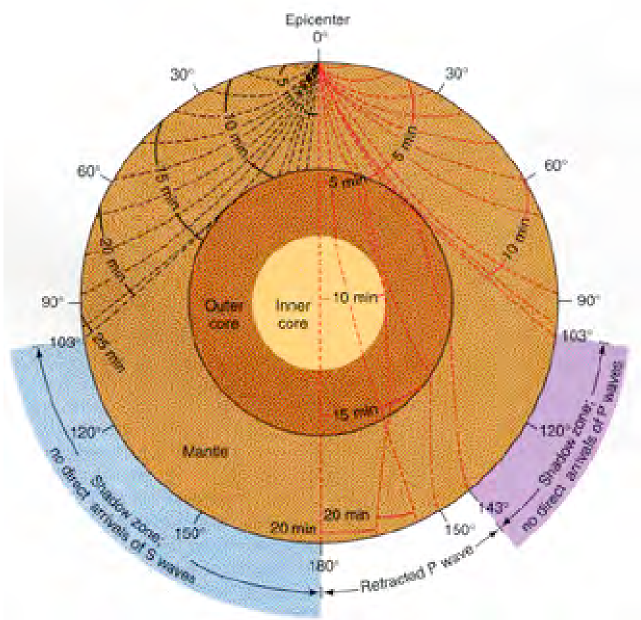
thickness continental crust: 20-70 km

thickness oceanic crust: 8 km



CMB

pronounced boundary at 2900 km depth



1) observation: S wave shadow zone (>103° no direct S waves)
inference: core must be (at least in part) liquid

2) observation: P wave shadow zone (103-143° no direct P waves)
inference: P waves slower in liquid, so refracted downward

3) observation: weak P waves in shadow zone
inference: P waves deflected by solid inner core (5100 km)

4) observation: P wave velocities in mantle imply density 3.3-5.5 g/cc
inference: core must be high density (10-13 g/cc), Fe only candidate

Other important features

LVZ

zone of reduced velocity from ~100-350 km
no evidence for different material (all peridotite) so infer near melting point
small amount of partial melt around grains
weak asthenosphere that is necessary for plate motions

400 km discontinuity

increase in both P and S wave velocities
olivine >> spinel structure (10 increase in density)

670 km discontinuity

origin not definitively known
pyroxene >> perovskite structure (may also affect spinel structures)

Elastic rebound theory and seismic risk

earthquake forecasting is based largely on the theory of elastic rebound
as plates move, if rocks don't slide easily then elastic energy stored
catastrophic release of energy

mechanisms for measuring strain accumulation
- surveying
- GPS
- SAR

Earthquake hazards

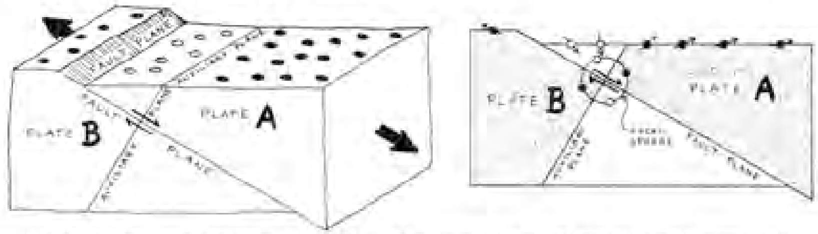
US hazard map
- most locations should make sense in terms of tectonic setting
  - west coast of U.S., Basin and Range
- New Madrid
  - 1811 M=8.3
  - ice-sheet unloading

Cascadia
- Factors favoring large quakes in ocean-continent setting
  - 1) faster subduction rate (less time for strain adjustment)
  - 2) shallow slab (more contact area)
  - 3) young slab age (empirical)
  - 4) thick sediments (empirical)
- All suggest that Cascadia might have large quakes, but none known
- How to estimate past events
  - > tree snags (treering dates indicate event ~1700)
  - > offshore deposits (turbidites)
- Suggest up to 1000 km might have slipped
- Confirmation: January 1700 tsunami records in Japan, M=9+

First motion studies

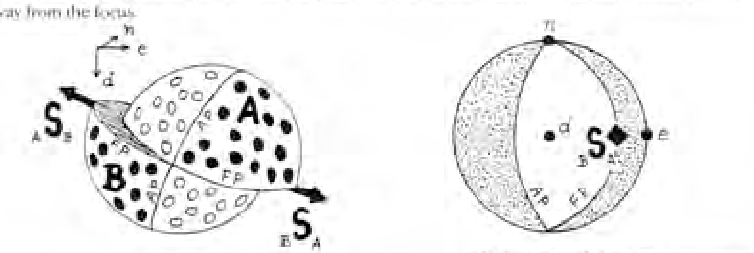
2D "beachball" on a flat earth
- shaded regions represent initial compression (up on vertical seismogram)

Box 6-7. Nonvertical Normal and Thrust Faults



The stations recording pushes (solid circles) can be separated from those recording pulls (open circles) by the lines of intersection in the earth's surface of the fault plane and auxiliary plane.

Solid and open symbols show pushes and pulls and arrows show directions of first motion toward or away from the focus.



NORMAL FAULT *(continued)*

3D applications

trace rays back (through earth model) to source and determine take off angle