Earth Science, 11e

Earthquakes and Earth’s Interior

Chapter 7
Earthquakes

General features

- Vibration of Earth produced by the rapid release of energy
- Associated with movements along faults
  - Explained by the plate tectonics theory
  - Mechanism for earthquakes was first explained by H. Reid
    - Rocks "spring back" – a phenomena called elastic rebound
    - Vibrations (earthquakes) occur as rock elastically returns to its original shape
Elastic rebound

Figure 7.5
Earthquakes

General features

- Earthquakes are often preceded by foreshocks and followed by aftershocks
Earthquakes

Earthquake waves

- Study of earthquake waves is called seismology
- Earthquake recording instrument (seismograph)
  - Records movement of Earth
  - Record is called a seismogram
- Types of earthquake waves
  - Surface waves
    - Complex motion
    - Slowest velocity of all waves
Seismograph

Figure 7.6
A seismogram records wave amplitude vs. time

Figure 7.7
Surface waves

F. Surface waves that are like ocean waves
Earthquakes

- Earthquake waves
  - Types of earthquake waves
    - Body waves
      - Primary (P) waves
        - Push-pull (compressional) motion
        - Travel through solids, liquids, and gases
        - Greatest velocity of all earthquake waves
Primary (P) waves

B. P waves traveling along the surface

Figure 7.8 B
Earthquakes

- Earthquake waves
  - Types of earthquake waves
    - Body waves
      - Secondary (S) waves
        - "Shake" motion
        - Travel only through solids
        - Slower velocity than P waves
Secondary (S) waves

D. S waves traveling along the surface

Figure 7.8 D
Earthquakes

- Locating an earthquake
  - Focus – the place within Earth where earthquake waves originate
  - Epicenter
    - Point on the surface, directly above the focus
    - Located using the difference in the arrival times between P and S wave recordings, which are related to distance
Earthquake focus and epicenter

Figure 7.2
Earthquakes

Locating an earthquake

- Epicenter
  - Three station recordings are needed to locate an epicenter
    - Circle equal to the epicenter distance is drawn around each station
    - Point where three circles intersect is the epicenter
A time-travel graph is used to find the distance to the epicenter.

Figure 7.9
The epicenter is located using three or more seismic stations.

Figure 7.10
Earthquakes

- Locating an earthquake
  - Earthquake zones are closely correlated with plate boundaries
    - Circum-Pacific belt
    - Oceanic ridge system
Magnitude 5 or greater earthquakes over a 10 year period

Figure 7.11
Earthquakes

Earthquake intensity and magnitude

• Intensity
  • A measure of the degree of earthquake shaking at a given locale based on the amount of damage
  • Most often measured by the Modified Mercalli Intensity Scale

• Magnitude
  • Concept introduced by Charles Richter in 1935
Earthquakes

Earthquake intensity and magnitude

- Magnitude
  - Often measured using the Richter scale
  - Based on the amplitude of the largest seismic wave
  - Each unit of Richter magnitude equates to roughly a 32-fold energy increase
  - Does not estimate adequately the size of very large earthquakes
Earthquakes

Earthquake intensity and magnitude

• Magnitude
  • Moment magnitude scale
    • Measures very large earthquakes
    • Derived from the amount of displacement that occurs along a fault zone
Earthquakes

- Earthquake destruction
  - Factors that determine structural damage
    - Intensity of the earthquake
    - Duration of the vibrations
    - Nature of the material upon which the structure rests
    - The design of the structure
Earthquakes

Earthquake destruction

- Destruction results from
  - Ground shaking
  - Liquefaction of the ground
    - Saturated material turns fluid
    - Underground objects may float to surface
  - Tsunami, or seismic sea waves
  - Landslides and ground subsidence
  - Fires
Damage caused by the 1964 Anchorage, Alaska earthquake

Figure 7.14
The Turnagain Heights slide resulted from the 1964 Anchorage, Alaska earthquake

Figure 7.21
Formation of a tsunami

Figure 7.18
Tsunami travel times to Honolulu

Figure 7.20
Earthquakes

Earthquake prediction

• Short-range – no reliable method yet devised for short-range prediction
• Long-range forecasts
  • Premise is that earthquakes are repetitive
  • Region is given a probability of a quake
Earth's layered structure

- Most of our knowledge of Earth’s interior comes from the study of P and S earthquake waves
  - Travel times of P and S waves through Earth vary depending on the properties of the materials
  - S waves travel only through solids
Possible seismic paths through the Earth

Figure 7.24
Earth's layered structure

Layers defined by composition

- Crust
  - Thin, rocky outer layer
  - Varies in thickness
    - Roughly 7 km (5 miles) in oceanic regions
    - Continental crust averages 35-40 km (25 miles)
    - Exceeds 70 km (40 miles) in some mountainous regions
Earth's layered structure

- Layers defined by composition
  - Crust
    - Continental crust
      - Upper crust composed of granitic rocks
      - Lower crust is more akin to basalt
      - Average density is about 2.7 g/cm$^3$
      - Up to 4 billion years old
Earth's layered structure

- Layers defined by composition
  - Crust
    - Oceanic Crust
      - Basaltic composition
      - Density about 3.0 g/cm$^3$
      - Younger (180 million years or less) than the continental crust
Earth's layered structure

- Layers defined by composition
  - Mantle
    - Below crust to a depth of 2900 kilometers (1800 miles)
    - Composition of the uppermost mantle is the igneous rock peridotite (changes at greater depths)
Earth's layered structure

- Layers defined by composition
  - **Outer Core**
    - Below mantle
    - A sphere having a radius of 3486 km (2161 miles)
    - Composed of an iron-nickel alloy
    - Average density of nearly 11 g/cm³
Earth's layered structure

Layers defined by physical properties

- Lithosphere
  - Crust and uppermost mantle (about 100 km thick)
  - Cool, rigid, solid
- Asthenosphere
  - Beneath the lithosphere
  - Upper mantle
  - To a depth of about 660 kilometers
  - Soft, weak layer that is easily deformed
Earth's layered structure

- Layers defined by physical properties
  - Mesosphere (or lower mantle)
    - 660-2900 km
    - More rigid layer
    - Rocks are very hot and capable of gradual flow
  - Outer core
    - Liquid layer
    - 2270 km (1410 miles) thick
    - Convective flow of metallic iron within generates Earth’s magnetic field
Earth's layered structure

Layers defined by physical properties

- Inner Core
  - Sphere with a radius of 1216 km (754 miles)
  - Behaves like a solid
Views of Earth’s layered structure

Figure 7.25
Earth's layered structure

- Discovering Earth’s major layers
  - Discovered using changes in seismic wave velocity
  - Mohorovicic discontinuity
    - Velocity of seismic waves increases abruptly below 50 km of depth
    - Separates crust from underlying mantle
Earth's layered structure

- Discovering Earth’s major layers
  - Shadow zone
    - Absence of P waves from about 105 degrees to 140 degrees around the globe from an earthquake
    - Explained if Earth contained a core composed of materials unlike the overlying mantle
Seismic shadow zones

Figure 7.26
Earth's layered structure

- Discovering Earth’s major layers
  - Inner core
    - Discovered in 1936 by noting a new region of seismic reflection within the core
    - Size was calculated in the 1960s using echoes from seismic waves generated during underground nuclear tests
Earth's layered structure

- Discovering Earth’s composition
  - Oceanic crust
    - Prior to the 1960s scientists had only seismic evidence from which to determine the composition of oceanic crust
    - Development of deep-sea drilling technology made the recovery of ocean floor samples possible
Earth's layered structure

Discovering Earth’s composition

- Mantle
  - Composition is more speculative
  - Lava from the asthenosphere has a composition similar to that which results from the partial melting of a rock called peridotite

- Core
  - Evidence comes from meteorites
    - Composition ranges from metallic meteorites made of iron and nickel to stony varieties composed of dense rock similar to peridotite
Discovering Earth’s composition

- Core
  - Evidence comes from meteorites
    - Iron, and other dense metals, sank to Earth’s interior during the planet’s early history
  - Earth’s magnetic field supports the concept of a molten outer core
    - Earth’s overall density is also best explained by an iron core
End of Chapter 7