

15:

Earthquakes & Earth's Interior



I. What is an earthquake?

- A. An earthquake is the vibration of Earth produced by the rapid release of energy
 - 1. Energy released radiates in all directions from its source, the **focus**
 - 2. Energy is in the form of waves
 - 3. Sensitive instruments around the world record the event
- B. Earthquakes and faults
 - 1. Movements that produce earthquakes are usually associated with large fractures in Earth's crust called **faults**
 - 2. Most of motion along faults can be explained by the **plate tectonics theory**
- C. **Elastic rebound**
 - 1. Mechanism for earthquakes was first explained by H.F. Reid (1906 San Francisco 'quake)
 - a. Rocks on both sides of an existing fault are deformed by tectonic forces
 - b. Rocks bend and store **elastic energy**
 - c. Frictional resistance holding the rocks together is overcome
 - d. Slippage at the weakest point (the focus) occurs
 - e. Vibrations (earthquakes) occur as the deformed rock "springs back" to its original shape (elastic rebound)
 - 2. Earthquakes most often occur along existing faults whenever the frictional forces on the fault surfaces are overcome
- D. Foreshocks and aftershocks
 - 1. Adjustments that follow a major earthquake often generate smaller earthquakes called **aftershocks**
 - 2. Small earthquakes, called **foreshocks**, often precede a major earthquake by days or, in some cases, by as much as several years

- II. **San Andreas fault**: an active earthquake zone
- A. San Andreas is the most studied fault system in the world
 - B. Displacement occurs along discrete segments 100 to 200 kilometers long
 - 1. Some portions exhibit slow, gradual displacement known as **fault creep**
 - 2. Other segments regularly slip producing small earthquakes
 - 3. Still other segments store elastic energy for hundreds of years before rupturing in great earthquakes
 - a. Process described as **stick-slip motion**
 - b. Great earthquakes should occur about every 50 to 200 years along these sections

III. **Seismology**

- A. The study of earthquake waves, seismology, dates back almost 2000 years to the Chinese
- B. **Seismograph**: instrument that record seismic waves
 - 1. Records the movement of Earth in relation to a suspended, stationary mass (inertia) on a rotating drum or magnetic tape
 - 2. More than one type of seismograph is needed to record both vertical and horizontal ground motion
 - 3. Records obtained are called **seismograms**
- C. Types of seismic waves
 - 1. **Surface waves**
 - a. Travel along outer part of Earth
 - b. Complex motion
 - c. Cause greatest destruction
 - d. Waves exhibit greatest **amplitude** (distance between crest and trough) and slowest velocity
 - e. Waves have the greatest **periods** (time interval between crests)
 - f. Often referred to as **long (L) waves**
 - 2. **Body waves**
 - a. Travel through Earth's interior
 - b. Two types based on mode of travel
 - 1. **Primary (P) waves**
 - a. Push-pull (compress and expand) motion, changing the volume of the intervening material
 - b. Travel through
 - 1. Solids
 - 2. Liquids
 - 3. Gases
 - c. The fastest seismic waves; generally, in any solid material, P waves travel about 1.7 times faster than S waves

2. **Secondary (S) waves**

- a. "Shake" motion at right angles to their direction of travel
- b. Temporarily change the shape of the material that transmits them
- c. Travel only through solids
- d. Slower velocity than P waves
- e. Slightly greater amplitude than P waves

IV. Locating the source of earthquakes

A. Terms

1. **Focus** - the place within Earth where earthquake waves originate
2. **Epicenter** - location on the surface directly above the focus

B. Epicenter is located using the difference in velocities of P and S waves

1. Three station recordings are needed to locate an epicenter
2. Each station determines the time interval between the arrival of the first P wave and the first S wave at their location
3. A travel-time graph is used to determine each station's distance to the epicenter
4. A circle with a radius equal to the distance to the epicenter is drawn around each station
5. The point where all three circles intersect is the earthquake epicenter

C. Earthquake belts

1. About 95 percent of the energy released by earthquakes originates in a few relatively narrow zones that wind around the globe
2. Major earthquake zones include the
 - a. **Circum-Pacific belt**, where most strong earthquakes occur
 - b. **Oceanic ridge system**

V. Measuring the size of earthquakes

A. Two measurements that describe the size of an earthquake are

1. **Intensity** – a measure of the degree of earthquake shaking at a given locale based on the amount of damage to structures
2. **Magnitude** – estimates the amount of energy released at the source of the earthquake

B. Intensity Scales

1. **Modified Mercalli Intensity Scale** was developed using California buildings as its standard
2. The drawback of intensity scales is that destruction may not be a true measure of the earthquake's actual severity

C. Magnitude scales

1. **Richter magnitude**

- a. Concept introduced by Charles Richter in 1935
- b. Richter scale
 1. Based on the amplitude of the largest seismic wave recorded
 2. Accounts for the decrease in wave amplitude with increased distance
 3. Largest magnitude recorded on a Wood-Anderson seismograph was 8.9
 4. Magnitudes less than 2.0 are not felt by humans
 5. Each unit of Richter magnitude increase corresponds to
 - a. A tenfold increase in wave amplitude
 - b. A 32-fold energy increase (compared to a 4.0, a 6.0 releases about 900 times as much energy)

2. Other magnitude scales

- a. Several “Richter-like” magnitude scales have been developed
- b. **Moment magnitude**
 1. Developed because none of the “Richter-like” magnitude scales adequately estimates the size of very large earthquakes
 2. Derived from the amount of **displacement** that occurs along a fault
 3. Calculated using
 - a. Average amount of displacement along the fault
 - b. Area of the rupture surface
 - c. Shear strength of the faulted block
 4. Has gained wide acceptance among seismologists and engineers

VI. Earthquake destruction

A. Amount of structural damage attributable to earthquake vibrations depends on

1. Distance from the epicenter (intensity and duration of the vibrations)
2. Nature of the material upon which the structure rests
3. Design of the structure

- B. Destruction from seismic vibrations
 - 1. Fault movement
 - a. The 1906 San Francisco earthquake produced relative movements of about 20 feet along fault breaks.
 - 2. Ground shaking
 - a. Soft sediments generally amplify vibrations more than solid bedrock
 - b. Regions within 20 to 50 kilometers of the epicenter will experience about the same intensity of ground shaking
 - 2. **Liquefaction** of the ground (Mexico City, San Francisco)
 - a. Unconsolidated materials saturated with water turn into a mobile fluid causing landslides (Valdez, Alaska)
 - b. Underground objects may float toward the surface
- C. **Tsunamis**, or seismic sea waves
 - 1. Destructive waves that are often inappropriately called “tidal waves”
 - 2. Can result from
 - a. Vertical displacement along a fault located on the ocean floor or
 - b. From a large undersea landslide triggered by an earthquake
 - c. Unusually large volcanic explosions, or
 - d. Unusually large meteorite impacts
 - 3. In the open ocean height is usually less than 1 meter
 - 4. In shallower coastal waters the water piles up to heights that occasionally exceed 30 meters
 - 5. Can be very destructive
- D. Landslides and ground subsidence
- E. Fire

VII. Can earthquakes be predicted?

- A. Short-range prediction
 - 1. Goal is to provide a warning of the location and magnitude of a large earthquake within a narrow time frame
 - 2. Research has concentrated on monitoring possible precursors – phenomena that precede a forthcoming earthquake such as measuring
 - a. Uplift
 - b. Subsidence
 - c. Strain in the rocks
 - 3. Currently, no reliable method exists for making short-range earthquake predictions

- B. Long-range forecasts
 - 1. Give the probability of a certain magnitude earthquake occurring on a time scale of 30 to 100 years, or more
 - 2. Based on the premise that earthquakes are repetitive or cyclical
 - a. Using historical records or
 - b. **Paleoseismology**
 - 3. Are important because they provide information used to
 - a. Develop the Uniform Building Code and
 - b. Assist in land-use planning

VIII. Seismic waves and Earth's structure

- A. The rather abrupt changes in seismic-wave velocities that occur at particular depths helped seismologists conclude that Earth must be composed of distinct shells
- B. Layers defined by composition
 - 1. Because of density sorting during an early period of partial melting, Earth's interior is not homogeneous
 - 2. Three principal compositional layers
 - a. **Crust** – the comparatively thin outer skin that ranges from 3 kilometers (2 miles) at the oceanic ridges to 70 kilometers (40 miles in some mountain belts)
 - b. **Mantle** – a solid rocky (silica-rich) shell that extends to a depth of about 2900 kilometers (1800 miles)
 - c. **Core** – an iron-rich sphere having a radius of 3486 kilometers (2161 miles)
- C. Layers defined by physical properties
 - 1. With increasing depth, Earth's interior is characterized by gradual increases in
 - a. Temperature – at a depth of 100 kilometers temperature is between 1200°C and 1400°C, whereas the temperature at Earth's center may exceed 6700°C
 - b. Pressure – with depth, increased pressure tends to increase rock strength
 - c. Density
 - 2. Depending on the temperature and depth, a particular Earth material may behave
 - a. Like a brittle solid
 - b. Deform in a putty-like manner, or
 - c. Melt and become liquid

3. Main layers of Earth's interior based on physical properties and hence mechanical strength
 - a. **Lithosphere** (sphere of rock)
 1. Earth's outermost layer
 2. Consists of the crust and uppermost mantle
 3. Relatively cool, rigid shell
 4. Averages about 100 kilometers in thickness, but may be 250 kilometers or more thick beneath the older portions of the continents
 - b. **Asthenosphere** (weak sphere)
 1. Beneath the lithosphere, in the upper mantle to a depth of about 600 kilometers
 2. Small amount of melting in the upper portion mechanically detaches the lithosphere from the layer below allowing the lithosphere to move independently of the asthenosphere
 - c. **Mesosphere** or lower mantle
 1. Between the depths of 660 kilometers and 2900 kilometers
 2. Rigid layer
 3. Rocks are very hot and capable of very gradual flow
 - d. **Outer core**
 1. An alloy (mixture) of mostly iron with some nickel
 2. Liquid layer
 3. 2270 kilometers (1410 miles) thick
 4. Convective flow within generates Earth's magnetic field
 - e. **Inner core**
 1. A mostly iron sphere with a radius of 3486 kilometers (2161 miles)
 2. Material is denser and stronger than the outer core
 3. Behaves like a solid

IX. Discovering Earth's major layers

A. **The Moho (Mohorovicic discontinuity)**

1. Discovered in 1909 by Andriaja Mohorovicic
2. Separates crustal materials from underlying mantle
3. Identified by a change in the velocity of P waves

B. The core-mantle boundary

1. Discovered in 1914 by Beno Gutenberg
2. Based on the observation that P waves die out at 105 degrees from the earthquake and reappear at about 140 degrees, but about 2 minutes later than expected – this 35 degree wide belt is named the P wave **shadow zone**
3. Characterized by bending (refracting) of the P waves
4. The fact that S waves do not travel through the core provides evidence for the existence of a liquid layer (core) beneath the rocky mantle

C. Discovery of the inner core

1. Predicted by Inge Lehmann in 1936
2. Region of seismic reflection and refraction within the core

X. Discovering Earth's composition

A. **Crust**

1. Thinnest of Earth's divisions
2. Varies in thickness
 - a. Exceeds 70 km in some mountainous regions
 - b. Thinner than 3 kilometers in some oceanic areas
3. Two parts
 - a. **Continental crust**
 1. Lighter
 2. Granitic rocks
 - b. **Oceanic crust**
 1. Denser
 2. Composed mainly of the igneous rock basalt

B. **Mantle**

1. Solid, rocky layer
2. Composed of rocks like **peridotite** (olivine & pyroxene)

C. **Core**

1. Thought to be mainly dense iron and nickel, like meteorites
2. Two parts
 - a. Outer core – molten
 - b. Inner core - solid