1

2 ***Chapter 11 – Earthquakes***

3 **What Is an Earthquake?**

- An earthquake is ground shaking caused by the sudden and rapid movement of one block of rock sliding past another
  - Rocks slide past one another along fractures in the crust called faults
  - Most earthquakes occur along preexisting faults
  - Most faults are *locked except* for brief, abrupt movements (earthquakes)

4 **What Is an Earthquake?**

- Earthquake
  - Rock slippage originates in the ground at the focus or hypocenter
  - The epicenter is the point on the ground surface directly above the focus
  - Stored up energy is released as seismic waves that radiate in all directions from the focus

5 **Earthquake hypocenter and epicenter**

6 **What Is an Earthquake?**

- Discovering the Causes of Earthquakes
  - Energy released from volcanic eruptions, massive landslides, and meteorites can generate earthquake-like waves—but these are usually weak
  - Over tens to hundreds of years, stress builds up from plate movement. Eventually, stress along the fault overcomes the frictional resistance, and slip initiates as the rocks break
    - The deformed rocks “snap back” to their original position in a process called elastic rebound

7 **Displacement of Structures Along a Fault**

8 **Elastic Rebound**

9 **What Is an Earthquake?**

- Aftershocks and Foreshocks
  - Numerous small earthquakes, called aftershocks, usually follow a major earthquake
    - Diminish in frequency and intensity in the months following
    - Although weaker than the main event, aftershocks often trigger the destruction of already weakened structures
  - Foreshocks are minor earthquakes that sometimes precede a major earthquake by days, weeks, or months

10 **Faults and Earthquakes**

- Earthquakes occur along both new and preexisting faults in places where differential stresses cause the crust to break
  - Normal—associated with divergent plate boundaries
    - Not associated with large earthquakes
  - Reverse and thrust—associated with convergent plate boundaries
    - In a subduction zone, the boundary forms a megathrust fault
    - Produce most of Earth’s powerful earthquakes, generate tsunamis
  - Strike-slip—associated with transform plate boundaries
    - Gradual displacement called fault creep
    - Ruptures result in major earthquakes

11 **Megathrust and Strike Slip Faults**

12 **Megathrust and Strike Slip Faults**

13 **Faults and Earthquakes**

- Fault Rupture and Propagation
  - Slippage along large faults does not occur instantaneously
    - Initial slip begins at hypocenter and propagates along the fault surface
    - Slippage adds strain to adjacent sections triggering more slippage
    - Slippage mainly travels in one direction
  - Fault slip is the amount of displacement on the fault surface

14 **Fault Propagation**

15 **Seismology: The Study of Earthquake Waves**

- Seismology is the study of earthquake waves
- Earliest studies of earthquake waves date back almost 2000 years to the Chinese

16 **Ancient Chinese Seismograph**

17 **Seismology: The Study of Earthquake Waves**

- Instruments That Record Earthquakes
  - Seismographs (or seismometers) record the movement of Earth in relation to a stationary mass on a rotating drum or magnetic tape
    - Based on principle of inertia
  - Earthquakes cause vertical and horizontal ground movement
    - More than one type of seismograph is needed to record and accurately describe intensity of shaking

18 **Principle of the Seismograph**

19 **Principle of the Seismograph**

20 **Seismology: The Study of Earthquake Waves**

- Seismic Waves
  - Records obtained are called seismograms
  - Types of seismic waves
    - Body waves travel through Earth’s interior
      - Primary (P) waves are compression waves
        - »Can travel through all materials
      - Secondary (S) waves are shear waves
        - »Can only travel through solid material
    - Surface waves travel in the rock layers just below Earth’s surface

21 **The Characteristic Motion of P Waves and S Waves**

22 **Body Waves Versus Surface Waves**

23 **Seismology: The Study of Earthquake Waves**

- Surface waves
  - Two general directions of motion
    - One causes the ground to move up and down, similar to the movement of ocean swells
    - The second causes the ground to move side to side
      - Causes the greatest destruction

24 **Two Types of Surface Waves**

25 **Seismology: The Study of Earthquake Waves**

- Body waves versus surface waves
  - P waves:
    - first to arrive at a recording station
    - have the lowest amplitude
  - S waves:
    - second to arrive at a recording station
  - Surface waves:
    - have the lowest velocity
    - last to arrive at a recording station
    - have the highest amplitude
    - cause the greatest property damage

26 **Typical Seismogram**

27 **Locating the Source of an Earthquake**

- Seismologists first locate the *epicenter*
  - Developed by using seismograms from earthquakes whose epicenters could easily be pinpointed

- Travel-time graphs were constructed
- Using travel-time graphs and *triangulation* we can locate an epicenter
  - Time interval between between first P wave and first S wave
  - Find location on graph where vertical separation between curves is equal to that time interval
  - Read the distance to the epicenter
  - Repeat with two or more seismic stations

28 **Triangulation**

29 **Triangulation**

30 **Triangulation**

31 **Determining the Size of an Earthquake**

- Two fundamentally different measurements are used to describe the size of an earthquake
  - Intensity: a measure of the amount of ground shaking at a particular location based on observed property damage
  - Magnitude: quantitative measurement of ground motion based on data from seismic records used to estimate of the amount of energy released at an earthquake's source

32 **Determining the Size of an Earthquake**

- Intensity scales
  - The Modified Mercalli Intensity scale was developed using California buildings as its standard
    - Developed in 1902 by Giuseppe Mercalli
    - Based on property destruction in a region
    - Values change based on the distance from the epicenter

33 **Modified Mercalli Intensity Scale**

34 **Seismic Intensity Map**

35 **Determining the Size of an Earthquake**

- Magnitude scales
  - Richter magnitude
    - Concept introduced by Charles Richter in 1935
    - The Richter scale is calculated by measuring the amplitude of the largest seismic wave (usually A wave) recorded on a seismogram
      - Logarithmic scale that accounts for the decrease in wave amplitude with increased distance
      - Each unit on the scale means a *10-fold* difference in *wave amplitude* and a *32-fold* difference in *energy released*

36 **Determining the Richter Magnitude of an Earthquake**

37 **Determining the Richter Magnitude of an Earthquake**

38 **Determining the Size of an Earthquake**

- Magnitude Scales
  - Moment magnitude (M_W) measures the total energy released during an earthquake
    - Newer scale:
      - Calculated by the average amount of slip on the fault, the area of the fault surface that slipped, and the strength of the faulted rock
    - Can also be calculated by modeling data from seismograms

39 **Annual Occurrence of Earthquakes with Various Magnitudes**

40 **Earthquake Destruction**

- Amount of destruction attributable to an earthquake varies based on:
  - Magnitude of the earthquake
  - Proximity of a populated area to the epicenter

41 **Earthquake Destruction**

- Destruction from Seismic Vibrations
  - The amount of damage to structures depends on:

- The earthquake *intensity*
- The *duration* of the vibrations
- The *nature of the material* beneath the structures
- The *nature of building materials* and *construction practices* of the region

42 **Comparing Damage to Structures**

43 **Earthquake Destruction**

- Destruction from Seismic Vibrations
  - Amplification of seismic waves
    - Soft sediments amplify seismic waves more than solid bedrock
  - Liquefaction
    - The phenomenon where loosely packed, waterlogged sediments behave as a fluid during the intense shaking of an earthquake

44 **Liquefaction**

45 **Liquefaction**

46 **Earthquake Destruction**

- Destruction from Seismic Vibrations
  - Seiches
    - Rhythmic sloshing of water in lakes, reservoirs, and enclosed basins
    - Can be dangerous to small watercraft or if the sloshing causes water to spill over the dams of reservoirs

47 **Earthquake Destruction**

- Landslides and Ground Subsidence
  - Ground shaking causes loose sediments on a slope to slump
  - Often the greatest damage from earthquakes
- Fire
  - Can start when gas and electrical lines are destroyed by an earthquake
  - Broken water lines make fire control nearly impossible

48 **Turnagain Heights Slide Caused by the 1964 Alaskan Earthquake**

49 **Earthquake Destruction**

- What Is a Tsunami?
  - A series of large ocean waves (“harbor waves”)
    - Most are generated by displacement from a megathrust fault
    - Resemble ripples from a pebble dropped into a pond
    - Advance across the ocean at 800 km/hr
    - In open water, the wave amplitude is less than 1 m and the wavelength can be larger than 700 m
    - Close to shore, the water “piles up” and some tsunamis can exceed 30 m in height

50 **Tsunami Generated by Displacement of the Ocean Floor**

51 **Earthquake Destruction**

- Tsunami damage from the 2004 Indonesian earthquake
  - The tsunami was caused by an undersea earthquake near Sumatra and is one of the deadliest natural disasters
- Japan tsunami
  - The tsunami generated from the 2011 Tohoku earthquake was 40 m high and a Pacific-wide event, affecting not only Japan but also the west coast of North America

52 **Tsunami Generated Off the Coast of Sumatra, 2004**

53 **Japan Tsunami**

54 **Earthquake Destruction**

- Tsunami warning system
  - Observations in the Pacific Ocean allow scientists to track tsunamis and issue appropriate warnings to affected areas
    - Seismic observatories report large earthquakes to the Tsunami Warning Center

        - A series of deep-water buoys in the Pacific Ocean detect energy released by earthquakes
        - Tidal gauges measure sea level rise and fall

55 **Tsunami Travel Times**

56 **Where do Most Earthquakes Occur?**

- About 95% of energy released from earthquakes originates along fault surfaces where tectonic plates interact
    - The zone of greatest seismic activity is called the circum-Pacific belt
    - The largest earthquakes occur along megathrust faults of convergent plate boundaries

57 **Where do Most Earthquakes Occur?**

- The *Alpine-Himalayan belt* is another region of strong earthquakes
    - Tectonic activity is attributed to the collision of the African and Indian Plates with the Eurasian Plate
- Divergent plate boundaries are associated with frequent but weak seismic activity
- Transform faults tend to generate large earthquakes on a cyclical basis

58 **Earthquake Belts**

59 **Damaging Earthquakes East of the Rockies**

- Six major earthquakes and several others have inflicted considerable damage in the central and eastern US
    - Three with estimated Richter magnitudes of 7.5, 7.3, and 7.8
    - Centered near the Mississippi River valley
    - Occurred on Dec. 16, 1811, Jan. 23, 1812, and Feb. 7, 1812
    - Destroyed the town of New Madrid, Missouri
        - Suggests potential major damage in Memphis' future
    - Aug. 31, 1886 in Charleston, SC, was the greatest historical earthquake in the eastern US

60 **Damaging Earthquakes East of the Rockies**

61 **Damaging Earthquakes East of the Rockies**

62 **Can Earthquakes Be Predicted?**

- Short-Range Predictions
    - The goal is to provide a warning of the location and magnitude of a large earthquake within a narrow time frame
    - Efforts to accomplish this in Japan, US, China, Russia
    - Research has concentrated on monitoring possible precursors of major earthquakes:
        - Monitor changes in ground elevation
        - Measure strain in the rocks
        - Measure changes in groundwater level
        - Frequency of foreshocks

63 **Can Earthquakes Be Predicted?**

- Short-Range Predictions
    - Must have a small range of uncertainty in regards to location and timing
        - Must produce few failures and false alarms
    - Currently, no reliable methods exist for making short-range earthquake predictions
    - Generally concluded that short-range prediction is not feasible

64 **Can Earthquakes Be Predicted?**

- Long-Range Forecasts
    - Give the probability of earthquakes of a certain magnitude occurring on a time scale of 30 to 100 years (or more)
        - Useful guide for building codes, dams, roadways, etc.
    - Based on evidence that many large faults break in a cyclical manner, producing earthquakes of roughly the same magnitude at roughly similar intervals

65 **Can Earthquakes Be Predicted?**

- Long-Range Forecasts
  - Seismic gaps are tectonically quiet zones along a fault where strain is currently building up
    - The stored strain will be released in a future earthquake
    - Strain can be estimated using known rate of plate movement
  - Paleoseismology is the study of prehistoric earthquakes
    - By digging a trench across a fault zone, scientists look for evidence of ancient faulting (mud volcanoes and offset sedimentary strata)

66 **Seismic Gaps: Tools for Forecasting Earthquakes**

67 **Paleoseismology: The Study of Prehistoric Earthquakes**

68

End of Chapter 11