1 ***Earthquakes***

***Earth*, Chapter 11**

2 **Earthquakes: summary in haiku form**

Built on shaky ground,
Memphis, south of New Madrid -
whole lotta shakin'...

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

4 **What Is an Earthquake?**

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

5 ***Earthquake focus and epicenter***

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8 **What Is an Earthquake?**

- Discovering the Causes of Earthquakes
  - Massive landslides, meteorites, and volcanic eruptions produce weak earthquakes
  - 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

9 **Displacement Along a Fault**

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12 **What Is an Earthquake?**

- Aftershocks and Foreshocks
  - Numerous small earthquakes, called aftershocks, usually follow a major earthquake
    - Aftershocks diminish in frequency and intensity in the months following
    - Although weaker than the main event, aftershocks can cause severe damage to already weakened structures
  - Foreshocks are minor earthquakes that sometimes precede a major earthquake by days, weeks, or months
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13 **Faults and Earthquakes**

- Types of faults
  - There are three major types of faults
    - Normal—associated with divergent plate boundaries
    - Reverse and thrust—associated with convergent plate boundaries
      - In a subduction zone, the boundary between the subducting and overlying plate is called a megathrust fault

»Produce most of Earth's powerful earthquakes
- Strike-slip—large faults associated with transform plate boundaries
  - –Small strike-slip faults associated with divergent plate boundaries
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17 **Faults and Earthquakes**

- Types of Faults
  - – San Andreas is the most studied fault system in the world
    - Some portions exhibit slow, gradual displacement known as fault creep
    - Other segments regularly slip, producing small earthquakes
    - Other segments remain stuck and store elastic energy for a few hundred years before they break loose, resulting in a major earthquake
      - –Process described as stick-slip motion
      - –Great earthquakes should occur about every 50 to 200 years along these sections
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18 **Faults and Earthquakes**

- Fault Rupture and Propagation
  - – Most faults are locked except for brief, abrupt movements
  - – Faults do not slip all at once
    - 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
-

19 **Fault Propagation**
20 **Fault Propagation**
21 **Fault Propagation**
22
23 ***Displacement produced by the 1906 San Francisco earthquake***
24 **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

25
26 ***Seismologist***

one who studies the shaking of Earth

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

- Instruments That Record Earthquakes
  - – Seismographs record the movement of Earth in relation to a stationary mass on a rotating drum or magnetic tape
  - – More than one type of seismograph is needed to record horizontal and vertical ground movement

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30 ***Seismograph designed to record vertical ground motion***
31 ***Seismographs***
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- Seismic Waves
  - Records obtained are called seismograms
  - Types of seismic waves
    - Surface waves travel in the rock layers just below Earth's surface
    - 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

33 **Body Waves Versus Surface Waves**

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

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

38 **Two Types of Surface Waves**

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- Seismic Waves
  - Body waves versus surface waves
    - P waves are the first to arrive at a recording station, but have the lowest amplitude
    - S waves are the second to arrive at a recording station
    - Surface waves have the lowest velocity, are the last to arrive at a recording station, and have the highest amplitude
      - Surface waves cause the greatest property damage

42 ***Primary (P) waves***

43 ***Secondary (S) waves***

44 ***Earthquake Waves***

45 ***Locating the source of earthquakes***

- Terms:
  - *Focus*
    - the place within Earth where earthquake waves originate
  - *Epicenter*
    - location on the surface directly above the focus
- Epicenter is located using the difference in velocities of P and S waves

46 ***Locating the source of earthquakes***

- Locating the epicenter of an earthquake
  - Three station recordings are needed to locate an epicenter
  - Each station determines the time interval between the arrival of the first P wave and the first S wave at their location
  - A travel-time graph is used to determine each station's distance to the epicenter

47 ***A seismogram records wave amplitude vs. time***

48 ***Locating the source of earthquakes***

- Locating the epicenter of an earthquake
  - A circle with a radius equal to the distance to the epicenter is drawn around each station
  - The point where all three circles intersect is the earthquake epicenter

49 ***A travel-time graph is used to find the distance to the epicenter***

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51 ***Epicenter is located using three or more seismographs***

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53 ***Locating the source of earthquakes***

- Earthquake belts
  - About 95 percent of the energy released by earthquakes originates in a few relatively narrow zones that wind around the globe
  - Major earthquake zones include:
    - the Circum-Pacific belt
    - Mediterranean Sea region to the Himalayan complex
    - the oceanic ridge system

54 ***Distribution of magnitude 5 or greater earthquakes, 1980 - 1990***

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56 ***Locating the source of earthquakes***

- Earthquake depths
  - Earthquakes originate at depths ranging from 5 to nearly 700 kilometers
  - Earthquake foci arbitrarily classified as:
    - *shallow* (surface to 70 kilometers)
    - *intermediate* (between 70 and 300 kilometers)
    - *deep* (over 300 kilometers)

57 ***Locating the source of earthquakes***

- Earthquake depths
  - Definite patterns exist
    - Shallow focus occur along the oceanic ridge system
    - Almost all deep-focus earthquakes occur in the circum-Pacific belt, particularly in regions situated landward of deep-ocean trenches

58 ***Relationship of earthquake depth to subduction zones***

59 **Determining the Size of Earthquakes**

- Two measurements are used to describe the size of an earthquake
  - Intensity: a measure of the degree of earthquake shaking at a given locale based on the amount of damage
  - Magnitude: an estimate of the amount of energy released at the source of the earthquake

60 ***Measuring the size of earthquakes***

- Magnitude scales
  - *Richter magnitude*
    - concept introduced by Charles Richter in 1935
  - *Richter scale*
    - Based on the amplitude of the largest seismic wave recorded
    - Accounts for the decrease in wave amplitude with increased distance

61 **Determining the Size of Earthquakes**

- Intensity scales
  - The Modified Mercalli Intensity scale was developed using California buildings as its standard
    - Based on property destruction in a region
    - Values change based on the distance from the epicenter
  - The drawback of intensity scales is that destruction may not be a true measure of the earthquake's actual severity

62 **Modified Mercalli Intensity Scale**
63 **Seismic Intensity Map, Loma Prieta 1989**
64 **Determining the Size of Earthquakes**
- 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 recorded on a seismogram
      - Logarithmic scale that accounts for the decrease in wave amplitude with increased distance
      - Magnitudes less than 2.0 are not felt by humans
      - Each unit of Richter magnitude increase corresponds to a tenfold increase in wave amplitude and a 32-fold energy increase

65 ***Santa Clara County Richter Scale***
66 **Determining the Richter Magnitude of a Quake**
67 **Determining the Size of Earthquakes**
- Magnitude Scales
  - Moment magnitude measures the total energy released during an earthquake
    - 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

68 ***Richter Scale of Earthquake Magnitude***
69 **Annual Occurrence of Earthquakes with Various Magnitudes**
70 ***Earthquake destruction***
- Amount of structural damage attributable to earthquake vibrations depends on:
  - *Intensity* and *duration* of the vibrations
  - Nature of the *material* upon which the structure rests
  - *Design* of the structure

71 ***Earthquake destruction***
- Destruction from seismic vibrations
  - Ground shaking
    - Regions within 20 to 50 kilometers of the epicenter will experience about the same intensity of ground shaking
    - However, destruction varies considerably mainly due to the nature of the ground on which the structures are built

72 ***Damage caused by the 1964 Anchorage, Alaska earthquake***
73 **Earthquake Destruction**
- Destruction from Seismic Vibrations
  - Amplification of seismic waves
    - Soft sediments amplify seismic waves more than solid bedrock
  - Liquefaction is the process where loosely packed, waterlogged sediments behave as a fluid during the intense shaking of an earthquake

74 **Liquefaction**
75 **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
  - Landslides
    - Hebgen Lake quake, 1959, M 7.5
    - Landslide buried Forest Service Campground, killing 26 campers

- Quake Lake created by landslide

76 ***Damage caused by the 1959 Hebgen Lake, Montana earthquake***

77 ***Damage caused by the 1959 Hebgen Lake, MT earthquake***

78 ***Damage caused by the 1959 Hebgen Lake, Montana earthquake***

79 ***Damage caused by the 1959 Hebgen Lake, Montana earthquake***

80 ***Damage caused by the 1959 Hebgen Lake, Montana earthquake***

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

82 **Earthquake Destruction**

- What Is a Tsunami?
  - A tsunami is a series of large ocean waves
    - Most are generated by displacement from a megathrust fault
    - In open water, the wave amplitude is less than 1 meter and the wavelength can be larger than 700 meters
    - Close to shore, the water “piles up” and some tsunamis can exceed 30 meters in height

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

84 **Earthquake Destruction**

- What Is a Tsunami?
  - 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

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

86 **Earthquake Destruction**

- What Is a Tsunami?
  - Japan tsunami
    - The tsunami generated from the 2011 Tohoku earthquake was 40 meters high and a Pacific-wide event, affecting not only Japan but also the west coast of North America

87 **Japan Tsunami**

88 **Earthquake Destruction**

- What Is a Tsunami?
  - 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
    -

89 **Earthquake Destruction**

90 **Tsunami Travel Times**

91 **Earthquake Belts and Plate Tectonics**

- 95 percent of energy released from earthquakes originates along the circum-Pacific belt
  - Most earthquakes occur along megathrust faults of convergent plate boundaries

92 **Earthquake Belts and Plate Tectonics**

- 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

93 **Earthquake Belts**

94 **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
- 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

95 **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

96 **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
      - Example: Building the Trans-Alaskan Pipeline over the Denali Fault

97 **Trans-Alaskan Oil Pipeline**

98 **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
  - 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)

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

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

101 ***Mid-continent Earthquakes:***
Life NOT on the Edge

102 ***Earthquake Hazards in the U.S.***

103 ***Way back in 1811 and 1812...***

104

105 ***Waves on the Mississippi***

106 ***1811 – 1812 estimated magnitudes***

107 ***Intensity Map for 1811 - 1812***

108 ***Relative Earthquake***
Energy Transfer:

109 ***t***

110 ***t***

111 ***1811 – 1812 estimated magnitudes***

112 ***Memphis***

113 ***AutoZone HQ, Memphis***

114 ***The Sterick Building, Memphis***

Completed in 1930, repainted in 1960's, vacant since 1980's

(NOT quake-code compliant)

115 ***The St. Louis Arch***
Completed in 1965, brought down in 20??

116 ***Earthquake Survival Kit***

do you know where yours is?

117 **End of Chapter**