1 **Introduction to**
Environmental Geology, 5e
Chapter 6
Earthquakes

2 **Volcanoes: summary in haiku form**
A volcano forms.
Magma comes to the surface -
explodes, if felsic.

3 **Case History: Haiti Earthquake**
- On January 12, 2010, a magnitude 7.0 earthquake struck Haiti and killed about 300,000 people
-
- A magnitude 6.3 earthquake struck the midlevel town of L'Aqila in 2009, many of the buildings collapsed, killing about 300 people. A similar earthquake in California probably would have caused no or very few deaths
-
- In Chili (February 27, 2010), a magnitude 8.8 earthquake, about 500 times as strong as the Haiti earthquake, killed about 800 people
-
- Buildings are not designed to withstand shaking or are built improperly, causing far more deaths

4

5 **Earthquakes**
- Violent ground-shaking phenomenon by the sudden release of strain energy stored in rocks
-
- One of the most catastrophic and devastating hazards
-
- Globally, most earthquakes are concentrated along plate boundaries
-
- USGS estimated about 1 million quakes annually
-
- Millions of people killed and billions of dollars in damage by catastrophic earthquakes

6 **Selected Major Earthquakes in the U.S.**
Table 6.1

7

8

9

10 **Causes for Earthquakes (1)**
- Stress and strain
-
- Stress: A force exerted per unit area within rocks or other Earth materials
-
- Strain: Deformation (size, shape, and orientation) of rock materials caused by stress
-
- Rock strength: Rock's ability to stand a magnitude level of stress before rupture
-
- Earthquake: Strain accumulated beyond rock strength

11 **Causes for Earthquakes (2)**
- Earthquake: Sudden release of strain energy caused by rock rupture (through faulting)
  –
- Earthquakes induced by human activities
  – Much smaller magnitude

- Reservoir-induced earthquakes
- Deep waste disposal and earthquake
- Nuclear explosions

12 **Earthquake Magnitude**

- Focus: The point at depth where the rocks ruptured to produce the earthquake
- Epicenter: The location on the surface of Earth above the focus
- Moment magnitude: Measure of the energy released by the earthquake. M_w = 2/3 log M_0 – 10.7, where M_0 is the seismic moment, estimated by examining the records from seismographs
- *Richter magnitude:* Named after the famous seismologist Charles Richter, describing the energy released by an earthquake. It is based upon the amplitude or size of the largest seismic wave produced by an earthquake

13 **Earthquake Magnitude Scale (1)**

- Richter scale: Related to the amplitude of ground motion
  - Increasing one order in magnitude, a tenfold increase in amplitude
  -
- Moment magnitude scale
  - Measuring the amount of strain energy released
  - Based on the amount of fault displacement
  - Applicable over a wider range of ground motions than the Richter scale
  -
- Earthquake energy: Increase one order in magnitude, about a 32-times increase in energy

14 **Earthquake Magnitude Scale (2)**

15

16

17

18

19 **Earthquake Intensity Scale (1)**

- Modified Mercalli Scale
  - 12 divisions
  - Qualitative severity measurement of damages and ground movement
  - Based on ground observations, instead of instrument measurement
  - Scale depending on earthquake’s magnitude, duration, distance from the epicenter, site geological conditions, and conditions of infrastructures (age, building code, etc.)

20

Table 6.4a

21

Table 6.4b

22

23

24

25 **Plate Boundary and Earthquakes**

- Most earthquakes concentrated along plate boundaries (interplate earthquakes), and nearly all catastrophic earthquakes are shallow earthquakes
-
- Divergent plate boundary: Shallow earthquakes
-
- Transform plate boundary: Shallow to intermediate earthquakes
-
- Convergent plate boundary: Wide zone of shallow, intermediate, and deep earthquakes; 80

percent of seismic energy released along the earthquake zone around the Pacific rim.

26 **Plate Boundary and Earthquakes**

Figure 6.5

27 **Major Intraplate Earthquakes (1)**

- Intraplate earthquakes: earthquakes occurs within the plate, away from plate boundaries
-
- Earthquakes occurred along the New Madrid seismic zone and in Charleston, SC

- In the eastern United States are generally more damaging due to stronger rocks that transmit earthquake waves more efficiently than rocks in the west
-
- Even in the “stable” interior of the North American plate, the possibility of future damage demands that the earthquake hazard in the area be considered construct power plants and dams

28 **Major Intraplate Earthquakes (2)**

- 1811–1812 New Madrid earthquake
  - Nearly destroyed the town of New Madrid
  - Killing unknown number of people
  - Rang church bell as far as in Boston
  - Forests flattened
  - Estimated magnitude >8.0
  -
- 1886 Charleston earthquake (M 7.5)
  - Killed 60 people
  - Damaged or destroyed most buildings of the city
  - Impacted area beyond 1000 km (620 mi)

29

30

31 **Earthquake Processes (1)**

- Faults
  - Fault types (normal, reverse, thrust, and strike-slip fault)
  - Mapping faults: Surface fault and buried subsurface fault
  - Fault activity (active, potentially active, and inactive faults)
  - Slip rate: The long-term rate of movement, recorded as millimeters per year (mm/yr) or meters per 1,000 years (m/ky)
  - Global plate boundaries, regional and local faults

32

33

34 **Earthquake Processes (2)**

- Faults almost never occur as a single rupture. Rather, they form fault zones
- Most long faults or fault zones, such as the San Andreas fault zone, are *segmented*
- Earthquake segment: Part of a fault zone has ruptured as a unit during historic and prehistoric earthquakes
- *Earthquake segment is most important to evaluation of the seismic hazard*
- Paleoseismology: The study of paleoseismicity (prehistoric seismic activity) from the geologic environment

35 **Active Faults**

Table 6.5

36 **Seismic Waves**

- Earthquake’s focus and epicenter
-
- Seismic wave propagation outward from the focus

- P wave: Compressional waves, travel fastest through all physical states of media
- S wave: Shear waves, travel slower than P wave, but faster than surface waves, only propagates through solid materials
- Surface waves: Moving along the Earth's surface, travels slowest, but causing most of the damage

37 **Measuring Seismic Waves**

- Seismograph or seismometer: Device to record the seismic waves
- Seismogram: The record of an earthquake
- Amplitude of seismic waves: Amplitude of ground vibration
- First arrival of seismic waves
  - Determine the time of earthquake
  - Distance to epicenter from a seismograph based on the difference in arrival time between P waves and S waves

38 **Material Amplification**

- Seismic waves travel differently through different rock materials
- Propagate faster through dense and solid rocks
- Material amplification: Intensity (amplitude of vertical movement) of ground shaking more severe in unconsolidated materials
- Seismic energy attenuated more and propagated less distance in unconsolidated materials
- Directivity: Another amplification effect, the intensity of seismic shaking increases in the direction of the fault rupture

39 **Ground Acceleration**

- Ground motion is related to the amplitude of seismic waves and its accelerations
- Measured by accelometers in terms of the acceleration of gravity
- Both vertical and horizontal accelerations
- M 6.0 to M 6.9 can have 0.3 to 0.7 g
- Structure designs target to withstand 0.6 to 0.7 g

40 **Supershear**

- Occurs when the propagation of rupture is faster than the velocity of shear waves or surface waves produced by the rupture, analogous to supersonic aircraft producing a sonic boom
- Produce shock waves that produce strong ground motion along the fault, resulting great damages
- Most likely to occur with strike-slip earthquakes that rupture a long straight fault segment

41 **Earthquake Cycles**

- Faulting and elastic rebound
- Stages of earthquake cycle
  - Inactive and aftershock stage
  - Stress accumulation stage
  - Foreshocks
  - Main shock (major earthquake)

- Dilatancy-diffusion model: The fault-valve mechanism hypothesizes that fluid (usually water) pressure rises until failure occurs, thus triggering an earthquake
- Earthquake cycle in space: Seismic gaps

42 **Effects of Earthquakes (1)**

- Primary effects
  – Ground shaking, tilting, and ground rupture
  – Loss of life and collapse of infrastructure
  –
- Secondary effects
  – Landslides, liquefaction, and tsunamis
  – Fires, floods, and diseases
-
- Tertiary effects
  – Social and psychological impacts

43 **Effects of Earthquakes: Tsunami**

- Japanese word for a “large harbor waves”
- Triggered by earthquake, submarine volcanic explosion, underwater landslide, asteroid impact
- Recent tsunami examples
  – 1960 Chile earthquake, killing 61 people in Hawaii
  – 1964 Alaska earthquake, killing about 130 people in AK and CA
  – 1993 earthquake near Japan, killing 120 people in Japan
  – 1998 Papua New Guinea earthquake, killing more than 2,100 people
  – 2004 Indonesian earthquake, killing about 250,000 people

44 **Earthquake Risks**

- Earthquake risks
  – Probabilistic methods for a given magnitude or intensity
  – Earthquake risk of an area
  – Earthquake risk of a fault segment
  –
- Seismic hazard maps
-
- Conditional probabilities for future earthquakes

45 **Earthquake Prediction**

- Long-term prediction
  – Earthquake hazard risk mapping
  –
- Short-term prediction (forecast)
  – Frequency and distribution pattern of foreshocks
  – Deformation of the ground surface: Tilting, elevation changes
  – Emission of radon gas
  – Seismic gap along faults
  – Abnormal animal activities?

46 **Response to Earthquake Hazards (1)**

- Hazard Reduction Programs
  – Develop a better understanding of the source and processes of earthquake
  –
  – Determine earthquake risk potential
  –
  – Predict effects of earthquakes
  –
  – Apply research results

47 **Response to Earthquake Hazards (2)**

- Adjustments to earthquake activities
  - Site selection for critical facilities
  - Structure reinforcement and protection
  - Land-use regulation and planning
  - Emergency planning and management: Insurance and relief measures

48 **Earthquake Warning Systems**

- Technically feasible: only about a minute warning
- Network of seismometers, sensing the first earthquake motion and sending a warning to critical facilities and public
- Warning system
  - Not a prediction tool
  - Can create a false alarm
- Better prediction and better warning system?

49 **Perception of the Earthquake Hazard**

- Public education and preparedness for the earthquake potential, even psychologically
- Pre-earthquake planning: what to do when struck
- During-earthquake: understand the situation and formulate a good strategy
- Post-earthquake emergency response
- Better engineering structural designs to minimize the future hazard risks

50 **Applied and Critical-Thinking Topics**

- What is the main lesson from the recent earthquakes in Italy and Haiti? How important is the wealth of a country to reducing the earthquake hazard?
- From your point of view, what can an individual citizen do to minimize the earthquake impact risks?
- What would be your approach to present info on earthquake hazard to people who knew very little about earthquake?
- Propose geologic scenarios that may change the global earthquake distribution patterns.

51 **End of the Road (and Chapter)**