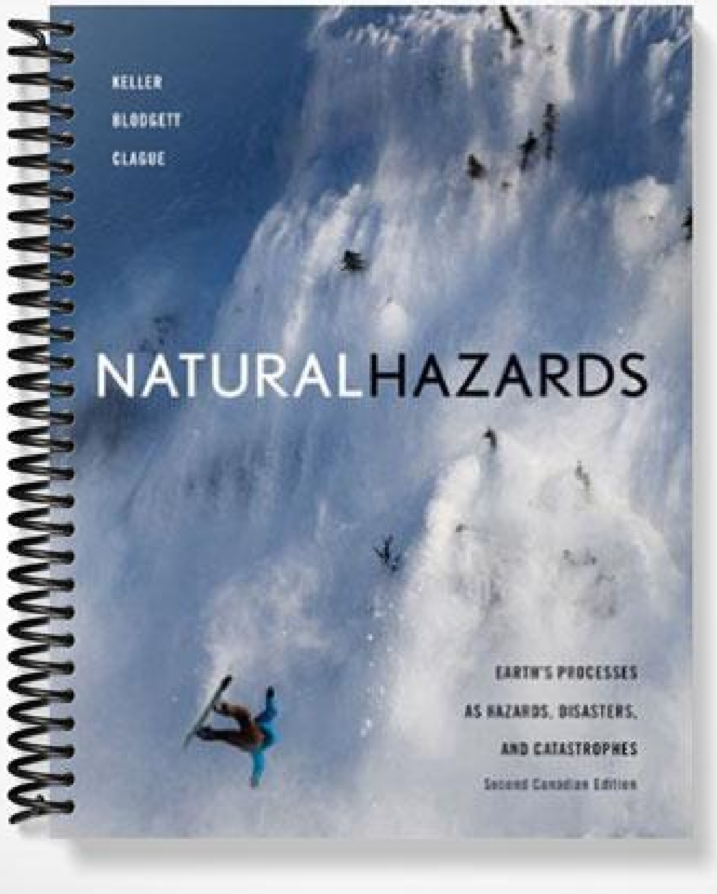
SOLUTIONS MANUAL



Chapter 2
Earthquakes

Learning Objectives

- Know what an earthquake is
- Understand how seismologists, scientists who study earthquakes, measure them
- Be familiar with earthquake processes, such as faulting, tectonic creep, and the formation and movement of seismic waves
- Know which regions are most at risk from earthquakes and why
- Know and understand the effects of earthquakes, such as shaking, ground rupture, tsunami, and liquefaction
- Identify how earthquakes are linked to other natural hazards such as landslides, fire, and tsunami
- Know the important natural service functions of earthquakes
- Know how people interact with and affect earthquake hazards
- Understand how people can minimize earthquake risk and take measures to protect themselves

Answers to Review Questions

1. What is the difference between the epicenter and focus of an earthquake? (p. 34, 35; Figure 2.3)

The epicenter is the point on the surface of the earth directly above where the ruptured rocks broke to produce the earthquake. The focus is the point of initial breaking below Earth's surface, which is directly below the epicenter.

2. What is moment magnitude? How is it related to the amount of shaking and the amount of energy released by an earthquake? (p. 36; Figure 2.4; Table 2.3)

The moment magnitude measures the size of an earthquake. Numerically it is similar to the more commonly reported Richter Scale, but this scale takes into consideration more geological data such as rock type, directivity and the area of rupture along the fault plane. An increase in one whole number to the next higher one represents a 10-fold increase in the amount of shaking and a 32-fold increase in the amount of energy released.

3. What is instrumental intensity? What is its relation to a shake map? (p. 37)

Instrumental intensity is information produced by seismograph stations regarding direct measurements of ground motion during an earthquake. This information is used to immediately produce a shake map, which shows both perceived shaking and potential damage.

4. Explain how faulting occurs. (p. 37)

Faulting occurs when one lithospheric plate moves past another plate, slowed by the friction along their boundaries. When the strain on the rocks exceeds their breaking point (referred to as their strength), the rocks suddenly move along a fault.

5. How are active and potentially active faults defined? (p. 41)

Active faults have moved during the Holocene Epoch (during the past 11,600 years) and potentially active faults show evidence of having moved during the Pleistocene epoch (the past 2.6 million years).

6. What is the difference in the rates of travel of P, S, and surface waves? How is this difference important in locating earthquakes? (p. 41-42)

P waves are primary waves and move at about 6 km (3.7 miles) per second, while S waves are secondary waves and move at about 3 km (1.9 miles) per second. The difference is important in locating earthquakes because scientists use the difference between the time the S waves and P waves arrive to determine the distance to the epicenter from the seismograph. Surface waves travel the slowest of all and are typically only felt by people who are close to the epicenter.

7. How do seismologists locate earthquakes? (p. 42-43)

Seismographs locate earthquakes by using the difference between arrival times of the S and P waves to calculate the distance from the earthquake, and by drawing a circle around the station corresponding to that distance. If three seismic stations are used, the circles corresponding to the distance from the epicenter should all intersect at one unique location, that of the epicenter. This method is called triangulation.

8. How does the depth of an earthquake affect ground shaking and damage? (p. 44)

As a general rule, the deeper an earthquake is, the less damage the earthquake incurs. This is because seismic waves lose some of their energy while traveling the distance to the surface.

9. What types of geologic materials amplify seismic waves? (p. 45)

Seismic waves typically slow as they move into less consolidated materials such as sand, alluvium or wet clay and mud. As they slow, some of the forward-directed energy is transferred to surface waves. This amplification increases the ground motion felt and thus there is greater the potential for damage.

10. Explain the earthquake cycle. (p. 47-48; Figure 2.19)

The earthquake cycle proposes that there is a drop in elastic strain after an earthquake and a re-accumulation of strain before the next event. This cycle includes the earthquake, aftershocks and a period of apparent inactivity as strain continues to build. Foreshocks may or may not precede the next event.

11. What are foreshocks and aftershocks? (p. 48)

Foreshocks are the small to moderate-sized earthquakes that precede the main earthquake. Aftershocks are smaller earthquakes that occur a few minutes to a year or more after the main earthquake and have their epicenter in the same general area as the mainshock.

12. Where are earthquakes most likely to occur in the world? In North America? (p. 48-49)

Earthquakes can occur anywhere on earth, however most earthquakes occur along the boundaries of tectonic plates. Small to medium sized earthquakes occur along the mid ocean ridges; larger earthquakes occur along subduction zones and transform margins. Quakes not associated with a plate boundary are called intraplate quakes. The west coast of North America along the San Andreas and further north along the Juan de Fuca subduction zone are likely to experience large magnitude quakes. Intraplate quakes occur along the St. Lawrence Seaway, the New Madrid zone in the Mississippi Valley, and throughout the Rocky Mountains.

13. List the primary and secondary effects of earthquakes. (p. 52)

Primary effects of earthquakes are ground shaking and ground rupture. Secondary effects include liquefaction, land-level changes, landslides, tsunami, fire, and disease.

14. What types of earthquakes occur at transform, convergent, and divergent plate boundaries? (p. 49)

- Transform: lithospheric plates are sliding horizontally past one another, causing strike-slip earthquakes
- Convergent: lithospheric plates are pushing into one another, causing thrust earthquakes
- Divergent: lithospheric plates are moving away from one another, causing dip-slip earthquakes.

15. How do plate boundary and intraplate earthquakes differ? (p. 51)

Intraplate earthquakes happen away from the plate boundaries and plate boundary earthquakes happen along or associated with a plate boundary.

16. Why are the largest earthquakes not always the most damaging? (p. 54)

Sometimes large earthquakes occur in areas of low population and therefore do not have the chance to harm as many people as an earthquake near a city.

17. Where does liquefaction occur and what are its effects? (p. 54; Figures 2.26, 2.27)

Intense seismic shaking can cause water-saturated loose sediment to change from a solid to a liquid. Liquefaction occurs at shallow depths. Some of the effects of liquefaction are building collapse, dam failure, surfacing of underground structures, eruption of sand volcanoes, and subsidence.

18. How can earthquakes be beneficial? (p. 56)

Earthquakes can be beneficial because they may expose economically valuable minerals or they may allow for better groundwater flow including the surfacing of springs. They uplift mountain ranges forming spectacular scenery.

19. How can humans cause earthquakes? (p. 56-57)

Humans can cause earthquakes by loading Earth's crust, by injecting liquid waste deep into Earth, or by creating underground nuclear explosions, bomb blasts, or anything that causes the ground to shake (even driving or playing music can generate seismic waves).

20. What kinds of information are useful in assessing seismic risk? (p. 58)

To estimate seismic risk a range of different types of information are needed. First, the earthquake potential needs to be known, and the history and recurrence frequency of earthquakes or specific magnitude should be determined. The thicknesses of different types of substratum with different shake potential need to be known, as does the ability of these materials to attenuate seismic waves. The types of construction for various buildings, bridges, roads, etc., need to be factored into the risk equation, as does population density, and information about any potential secondary hazards such as nuclear and other power plants having problems, potential for fires from gas lines, etc.

21. What kinds of phenomena may be earthquake precursors? (p. 61)

Micro-earthquakes, strange animal behavior, deformation of ground surface, seismic gaps along faults, water level changes in wells and geophysical and geochemical changes within Earth may all be signs of an earthquake.

22. What is the difference between an earthquake prediction and a forecast? (p. 60)

A forecast states that an earthquake of a specified magnitude has a certain probability of occurring in an area within a specified number of years. A prediction specifies that an earthquake of a given magnitude will occur in a defined region within a restricted period of time.

23. How can a community prepare for an earthquake? (p. 65)

Communities may locate critical facilities in safer areas, they may use structural protection through establishment of building codes, they may use education, or they may increase insurance and relief measures. Education and drills are important for families, schools, and other public groups to carry out. Also, having several days canned food and water on hand in your home, along with a portable radio, good batteries, and a first aid kit are essential since rescue personnel may be overwhelmed initially.

24. What is seismic retrofitting? (p. 65)

Retrofitting is making engineering changes to existing critical structures like tall buildings and bridges to make them better able to withstand shaking from earthquakes.

Answers to Critical Thinking Questions

1. You live in an area where a large earthquake might happen. The community is debating the merits of developing an earthquake warning system. Some people worry that false alarms will be common; others argue that the cost of the system is far greater than the benefits it provides. What are your views on these points? Do you think the public should pay for an earthquake warning system, assuming such a system is feasible? What are the potential implications of not developing a warning system if a large earthquake results in damage that could otherwise have been partially avoided?

The first thing to do is to identify potential areas of long-term earthquake problems. Construction of earthquake-safe buildings and an awareness of long-term predictions are necessary. As far as a true warning system is concerned, you cannot predict an earthquake within days, but you possibly could within hours or minutes. This time frame would not allow people to move out of the way of all danger, so there must be an immediate safety plan (where to go if there is an earthquake, how to position yourself, etc.) in effect as well. Therefore, an earthquake warning system should be put into effect in concert with public education of an immediate safety plan, which should be financed by public officials. Trains, nuclear plants, and other facilities may have time to shut down if a warning system were in place, saving many lives. There needs to be much debate about what the responsibility of elected officials and government should be and at what cost. Certainly government has the responsibility of proper zoning, building codes and land use planning. Individuals must be educated and prepared for the eventuality of an earthquake if they live in this type of hazard area, because the reality of the situation is that government simply cannot adequately be prepared to immediately response to everyone and some preparedness for survival initially must remain the responsibility of individuals.

2. You are considering buying a house in Victoria, British Columbia. You know that large earthquakes can occur in the area. What questions would you ask before purchasing the home? For example, consider the effects of earthquakes, the type of rock

or sediment underlying the property, and the age of the house. What might you do to protect yourself both financially and physically if you decide to buy the house?

You should first find out when the house was built. If it is an older house, have - renovations been done to retrofit it to current earthquake standards? If it is a newer house, was it built in accordance with the earthquake building code? Find out what type of soil and/or bedrock the house was built on. This information should be forthcoming from your realtor, but if not, it is available from the B.C. Geological survey. If an earthquake occurs, certain types of soil can turn mushy and fail—an event called liquefaction. Ask for an expert geological hazard assessment as part of the purchase package. To protect yourself after buying a house, you can purchase earthquake insurance and you can also secure certain items in your house to prevent any damage during an earthquake (such as strapping water heaters to the wall, securing bookcases, shelving units, and kitchen dishes/cabinets).

3. You are working in a developing country where most of the homes are unreinforced and built out of bricks. The last damaging earthquake in the area happened 200 years ago and killed thousands of people. How would you describe the earthquake risk to your family members who live there with you? What steps could you take to reduce that risk?

I would study the area and determine the frequency of earthquakes in the area; perhaps the last earthquake was a 10,000-year quake. After that I would determine the likelihood that these people would have to deal with another in their lifetime. If these people do not, then the benefits of more affordable housing are well worth the savings at this point in time. In this case, the benefits outweigh the costs. However, if they are very likely to experience an earthquake then I would suggest building homes out of more sturdy material or trying to convince people to move onto more stable ground.

Suggested Activities

1. Find a water-saturated clay-mud and put it in a fish tank with model towns inside (including building, poles, etc.). Shake the tank to mimic an earthquake and watch the effects of liquefaction.

2. Watch Hollywood 'disaster' movies of earthquakes (i.e. 2012) and make a list of the inconsistencies between what you have learned and what the moviemakers present. Discuss what effect Hollywood may have on people's perception of earthquakes.

3. Collect daily epicenter information from the USGS website and plot the epicenter locations on a map of the world. Look for correlations between these quakes and the location of plate boundaries.

Additional Resources

Print Resources Dealing with Earthquakes

Bolt, B.A. 1999. *Earthquakes*, 4th Ed. New York: W.H. Freeman.
Boraiko, A.A. 1986. Earthquake in Mexico. *National Geographic* 169:654–675.
California Division of Mines and Geology. 1990. The Loma Prieta (Santa Cruz Mountains) earthquake of October 17, 1989. Special Publication 104.
Coburn, A., and Spence, R. 1992. *Earthquake Protection.* New York: John Wiley & Sons.
Dowrick, D.J. 2003. Earthquake risk reduction. West Sussex, England: John Wiley and Sons.
National Research Council. 2003. Preventing earthquake disasters: the grand challenge in earthquake engineering. Washington, D.C.: National Academy of Sciences.
Reiter, L. 1990. *Earthquake Hazard Analysis.* New York: Columbia University Press.
Richter, C.F. 1958. *Elementary Seismology.* San Francisco: W.H. Freeman, 137–138.
U.S. Geological Survey. 1989. *Lesson learned from the Loma Prieta earthquake of October 17, 1989.* Circular 1045.
U.S. Geological Survey. 1907. *The San Francisco Earthquake and Fire of April 18, 1906.* U.S. Geological Survey Bulletin 324. (A through description of the damage resulting from the earthquake and fire of 1906, including many black and white photographs and first-hand descriptions—rare book).
Verney, P. 1979. *The Earthquake Handbook.* London: Paddington Press.
Wallace, RE. (ed.). 1990. *The San Andreas Fault system, California.* U.S. Geological Survey Professional Paper 1515.

Non print Resources Dealing with Earthquakes

Videos and DVDs

Cascadia: The Hidden Fire, 2004, Global Net Productions, 60 min.

Hidden Fury: The New Madrid Earthquake Zone. 1993. Bullfrog Films, 27 min.

The Day the Earth Shook. 1995. NOVA, 55 min.

The Earth Revealed—Earthquakes. 1992. Annenberg CPB Project, 30 min.

Killer Quake. 1994. NOVAJKCET-TV, 60 min.

Loma Prieta Earthquake. 1992. U.S. Geological Survey, 53 min.

When the Earth Quakes. 1990. National Geographic, 28 min

Quake Hunters: Tracking a Monster in the Subduction Zone, 1998, Canadian Broadcasting Corp, Toronto, 53 min.

Web Sites

Canada Hazard Information Service
http://earthquakescanada.nrcan.gc.ca/index_e.php

Information on earthquakes in Canada from Natural Resources Canada

U.S. Geological Survey Earthquake Hazards Program
http://earthquake.usgs.gov
Homepage of the U.S. Geological Survey Earthquake Hazards Program

http://neic.cr.usgs.gov/
Site that posts real time current earthquake activity as the earthquakes occur.

U.S. Geological Survey: Earthquakes
http://pubs.usgs.gov/gip/earthq1/
A general interest publication from the USGS

U.S. Geological Survey: Earthquake List
http://earthquake.usgs.gov/eqcenter/recenteqsww/Quakes/quakes_all.php
A nearly real-time list of earthquakes

University of Washington
http://www.ess.washington.edu/recenteqs/latest.htm
University of Washington, Geophysics Program, earthquake information for the Pacific Northwest

Global Earthquake Response Centre
http://www.earthquake.org/

Earthquakes
www.iris.edu/quakes/quakes.htm
Information on earthquakes from the Incorporated Research Institutions for Seismology (IRIS)

Organizations Dealing with Earthquakes

Natural Resources Canada – Earthquake Hazard Information
http://earthquakescanada.nrcan.gc.ca/hazard/index_e.php

- Ottawa, Ontario (Eastern office)
- Sidney, British Columbia (Western office)

Provincial Emergency Program (BC)
http://www.pep.bc.ca/hazard_preparedness/Earthquake_Information.html

California Institute of Technology, Seismological Laboratories

http://www.gps.caltech.edu/seismo/

University of Utah Seismograph Stations

http://www.quake.utah.edu/