12.1 Earthquakes

In a place where earthquakes are common, it is not unusual to feel the ground shake. You might notice tiny ripples in your juice glass at breakfast and then you might feel small vibrations through your chair. Soon it's quiet again. Chances are good it was just a common, small earthquake. However, these vibrations might be a foreshock. A **foreshock** is a small burst of shaking that occurs before a large earthquake. Read on to find out more about earthquakes.

What is an earthquake like?

A big earthquake

During an earthquake, strong shaking makes the ground move up and down and back and forth. During the strongest earthquakes, it's nearly impossible to stand up. Large cracks may open up in the ground and the ground may heave up or sink. If the ground becomes saturated with water, the shaking soil might act like a liquid in a process called *liquefaction*. This causes the waterlogged soil to engulf buildings as they sink into the ground. The largest U.S. earthquake struck Alaska in 1964 and lasted for four minutes (Figure 12.1).

Foreshocks and aftershocks

Foreshocks can occur days before an earthquake hits, or just minutes before. Foreshocks get closer together just before an earthquake. In 1964, people had almost no warning because the foreshocks arrived only a few seconds before the earthquake. A small tremor that follows an earthquake is called an **aftershock**. Aftershocks can occur hours or even days after an earthquake. The time between aftershocks gets longer as time passes after an earthquake.

Most quakes are small

Most earthquakes are not as large as the Alaskan one. Many earthquakes are so small they can only be detected by scientific instruments.

Figure 12.1: *The 1964 Alaska earthquake was the longest ever recorded and the largest ever recorded in the United States.*

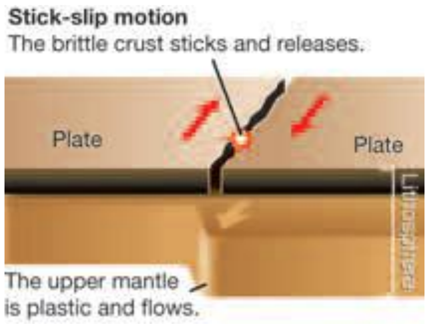
What causes earthquakes?

What is a an earthquake?

What exactly is an earthquake? An **earthquake** is the movement of Earth's crust due to the release of built-up potential energy (stored energy) between two stuck lithospheric plates.

Plates stick together, then break

Lithospheric plates on Earth's surface slide past each other. As this happens, the plates may stick together due to friction. Often the brittle crust will stick near the surface. However, the plastic upper mantle continues to flow underneath. *Plastic* here means "able to change shape without breaking," like modeling clay. With the crust stuck and the upper mantle moving below, the rocks at plate boundaries stretch or compress. As a result, potential energy builds in the plate. When potential energy exceeds the strength of the rock and friction—BANG!—the rock breaks and slips. This type of motion is called *stick-slip motion.*



Stress relief for plates

The sudden release of potential energy when plates "slip" causes earthquakes. In this sense, an earthquake is a stress reliever for lithospheric plates. However, the relief is only temporary. Potential energy starts building up again as soon as the quake ends.

Parts of an earthquake

The point below the surface where the rock breaks is called the earthquake **focus**. As soon as the rock breaks, there is movement along the broken surface. The broken surface is called a **fault**. The energy of the movement is spread by *seismic waves*. The seismic waves from an earthquake are usually strongest at the **epicenter**, the point on the surface right above the focus (Figure 12.2).

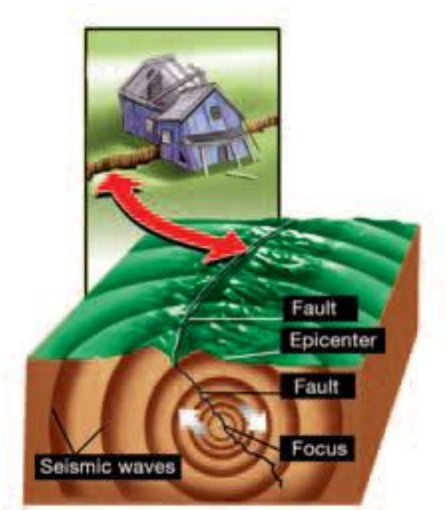


Figure 12.2: *The focus, epicenter, and seismic waves of an earthquake occurring at an active fault*

Stick-slip motion

Three conditions

The event of an earthquake is just like what happens when you try to open a stuck door. Both situations involve stick-slip motion. Think about trying to open a stuck door. You pull and pull and then... Bang! The door flies open (Figure 12.3). Three conditions are needed for stick-slip motion.

1. Two objects that are touching each other, where at least one of the objects can move.
2. A force (or forces) that will cause the movement.
3. Friction strong enough to temporarily keep the movement from starting. *Friction* is a force that resists slipping when two objects rub against each other (Figure 12.4).

A stuck door

In the stuck-door example, the two objects are the door and its frame. The force that will cause movement is you pulling on the door. The friction might be caused by moisture making a wooden door swell so that it jams in the door frame. You have to pull hard to overcome the friction. The loud bang you hear when the door opens is some of your pulling energy changed to sound energy as the door vibrates.

Earthquakes

As you've learned, an earthquake is a form of stick-slip motion because lithospheric plates slide past each other and get stuck. Eventually, the stuck plates slip and an earthquake occurs. The movement of lithospheric plates causes earthquakes at all three kinds of plate boundaries (divergent, convergent, and transform fault) and even within plates. Review the different types of plate boundaries in Section 11.3.

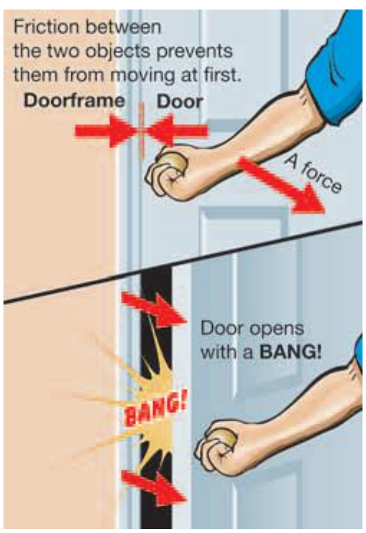


Figure 12.3: *A stuck door is an example of stick-slip motion.*

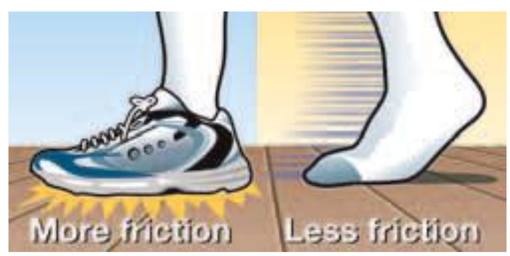


Figure 12.4: *There is more friction between a sneaker and a gym floor than between a sock and the gym floor.*

Lithospheric plates have many sections

Sections of plate boundaries

Although a lithospheric plate moves as a single unit, its boundary acts as though it were made of many sections. A line of grocery carts is a good analogy of lithospheric plate movement (Figure 12.5). A line of grocery carts moves along as a single unit, but there are small movements between each cart. When a person pushes the back end of a line, the carts at the front end remain still for a moment. It takes some time for the first cart to push the second, the second to push the next, and so on, until eventually, the front cart starts to move.

The San Andreas Fault

A lithospheric plate may be thousands of kilometers across. Therefore, it takes a long time for movement on one end of the plate to affect a section further away. Like each cart in a line of carts, each section of a plate can move before or after other sections. For example, parts of the San Andreas Fault can be stuck together and other parts may move at any time. An earthquake happens each time a plate section moves, but only in the section that moved.

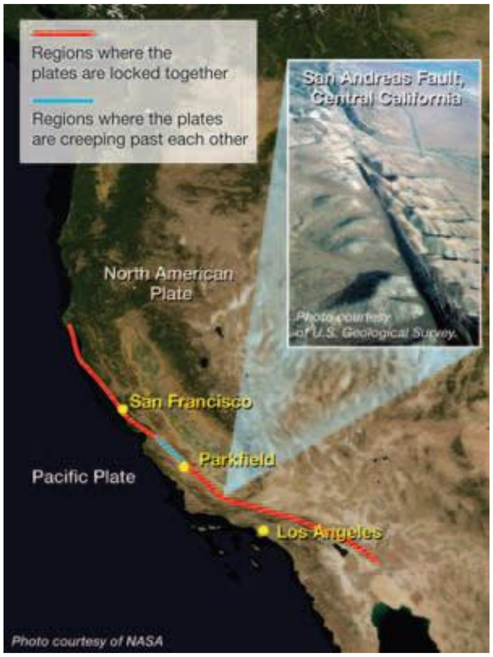


Figure 12.5: *A moving line of grocery carts is like a moving lithospheric plate.*

When do earthquakes occur?

Frequency and strength

Imagine two sections along the same fault. The first section has earthquakes a few times a year. The earthquakes are mild because relatively little energy is released during each quake. These frequent earthquakes release potential energy before it can build up to a high level. Now, let's say that earthquakes occur only once every 20 years in the second section. The long time period between earthquakes allows a great deal of potential energy to build up. Earthquakes in this section are likely to be devastating.

One earthquake may trigger others

It is common for an earthquake in one section of a fault to cause an earthquake in a neighboring section. Imagine two neighboring plate sections. One section is ahead of the other along the fault in the direction of plate movement. Both sections have built up a lot of potential energy. Then, an earthquake occurs in the front section, reducing its potential energy. Now there is an energy difference between the first and second section. This difference may trigger a new earthquake in the second section. It's common for one earthquake to have a ripple effect along a fault.

Earthquakes in the middle of plates

Throughout Earth's history, lithospheric plates have been torn apart, added to, and joined with other plates. As a result of this reshaping, there are old plate boundaries inside of the plates we see today. These old boundaries are now faults inside of plates. The New Madrid Fault, for example, is a fault zone within the North American Plate (Figure 12.6). This zone is an "old" plate boundary that can break when the North American crust flexes as a result of plate tectonic activity. This can result in a major earthquake, such as the New Madrid events in 1811 and 1812.

Figure 12.6: *The New Madrid Fault, a fault zone within the North American Plate.*

Seismic waves

Seismographs An earthquake converts potential energy into kinetic energy (the energy of motion) in the form of seismic waves. The waves start underground at the earthquake focus and radiate in all directions. Seismic waves are usually recorded and measured by a **seismograph**. The recordings indicate the arrival time, type, and strength of the waves. Seismographs are located around the world at seismic stations on land and in the oceans. Seismographs can look like large drums covered in paper (see above) or the waves can be recorded by computers (Figure 12.7).

Body waves

Seismic waves inside Earth are called **body waves**. The two main types of body waves are P-waves and S-waves. P-waves are faster and arrive first at a seismic station (Figure 12.7). They are fast because the rock through which they travel moves in the same direction that the P-waves move. S-waves travel more slowly because they cause the rock to move in a side-to-side motion. The speed at which body waves travel depends on the density and composition of the material they are traveling through. Waves travel faster in cool, dense material and slower in hot, less-dense material. The waves may also bend or be reflected when they contact different materials.

Surface waves

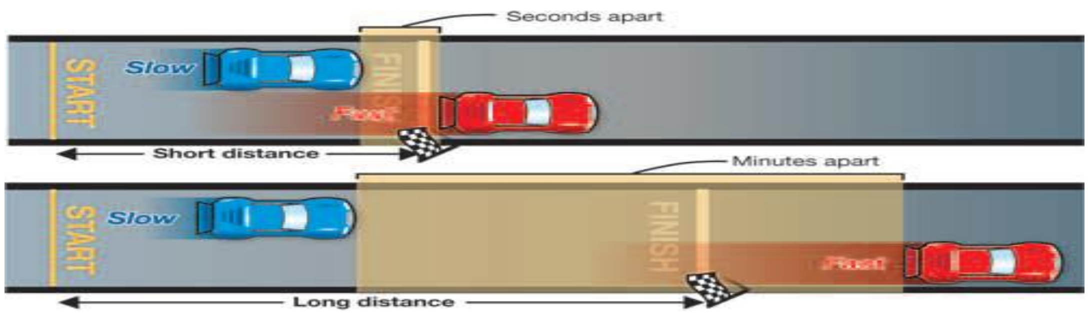
When seismic waves reach the surface, they become **surface waves**. Surface waves are slower than body waves, but they cause more damage. Surface waves can move up and down (like waves on the ocean), or from side to side, often causing buildings to collapse.

Figure 12.7: *After an earthquake occurs, the first seismic waves recorded will be P-waves. S waves are recorded next, followed by the surface waves.*

Locating the epicenter of an earthquake

A seismic waves "race"

The arrival times of P- and S-waves at a seismic station can be used to locate an earthquake's epicenter (Figure 12.8). This analogy explains how it's done. In a car race, all cars start together. In time, the fastest car gets ahead of the slowest car. The longer the race, the further ahead the faster car gets. Like fast and slow cars, P- and S-waves have different speeds. The difference in the arrival time between P- and S-waves determines the distance to the epicenter from the seismic station. The larger the difference in arrival time, the farther the epicenter is from the station.



Three seismic stations are needed

At least three stations are needed to locate the epicenter. First, each station determines the distance to the epicenter based on the P- and S-wave arrival times. Then each station draws a circle around its location on a map. The radius of each circle is based on the calculated distance to the epicenter. The edge of each station's circle represents all of the possible locations of the earthquake from that station. When all three circles are drawn on the same map, they will cross at a single point—the epicenter.

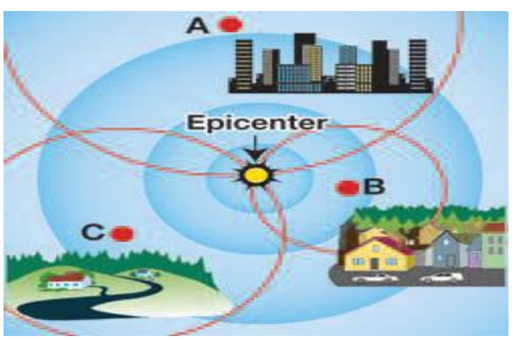


Figure 12.8: *An epicenter is located using data from three seismic stations.*

A seismic mystery solved by soccer

Many signals at one time

Garrett Euler was puzzled. Earthquake-like signals were arriving at all of his 32 seismic stations at the same time. Euler, a graduate student at Washington University, had traveled to the Republic of Cameroon in Africa to set up a network of seismic stations (Figure 12.9). By recording seismic waves, Euler hoped to learn more about Earth's crust and upper mantle.

Usually seismic waves arrive at different times

The strange signals reaching his stations made no sense. When an earthquake occurs, seismic waves reach different stations at different times, depending on the distance from the station to the epicenter. Only if the earthquake was on the opposite side of Earth could you get signals arriving at multiple stations at the same time. But Euler checked and found that no other seismologists had reported earthquakes at the same time. What was going on? What kind of activity could produce a seismic signal like this
(Figure 12.9)?

Seismic soccer?

Euler's girlfriend Katy Lofton had a hypothesis. She knew that soccer was popular in Cameroon. A quick check showed that an important soccer tournament, the African Cup of Nations, was played during the time of the strange signals. By checking game records, Euler was able to show that each burst of seismic signals matched the time each Cameroonian goal occurred! The source of the strange signal had been found. But, how did that signal get to all the stations at the same time? The answer to that part of the mystery is radio and television.

Goal!

These games were so popular that they were broadcast all over Cameroon. Radio and television allowed fans to experience the thrill of each goal in villages and cities all over the country at the same instant. Cameroonians cheered and stomped throughout their country, producing signals from countless "mini-epicenters."

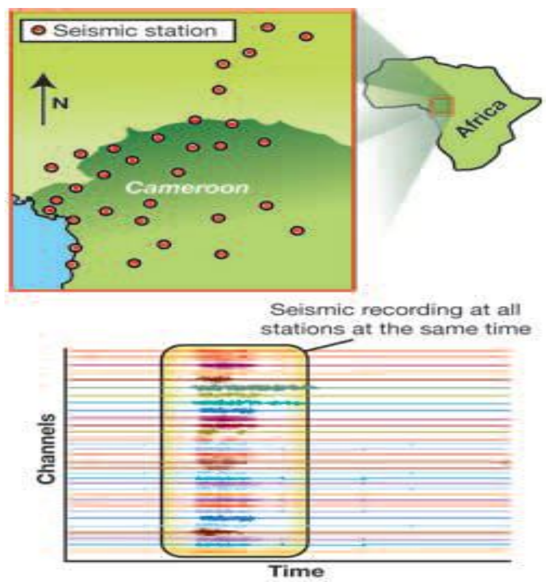


Figure 12.9: *Garrett Euler recorded seismic waves at the same time at all of his 32 seismic stations located in the Republic of Cameroon*

Measuring earthquakes

The Richter scale

The **Richter scale** ranks earthquakes according to their magnitude of the seismic waves recorded on a seismograph. Seismic wave amplitude increases ten times for each Richter magnitude change. For example, a magnitude 6.3 earthquake has a wave amplitude that is ten times greater than a magnitude 5.3 earthquake. The largest recorded earthquake occurred in Chile in 1960 (Figure 12.10). It was off the Richter scale. Seismologists estimated this quake to have been magnitude 9.5.

The Richter Scale:

Level	Magnitude	Description of what may occur
Micro	Less than 2.0	Barely felt, but recorded by seismographs
Very minor	2.0–2.9	Recorded but not felt by most people
Minor	3.0–3.9	Little damage but felt by people
Light	4.0–4.9	No serious damage, objects shake
Moderate	5.0–5.9	Major damage to poorly-designed buildings
Strong	6.0–6.9	Serious damage over a 100-km area or less
Major	7.0–7.9	Serious damage over a larger area
Great	8.0–8.9	Serious damage over several hundred km
Rare great	9.0 or greater	Serious damage over several thousand km

Damage caused by the 1960 Chile earthquake

Photo courtesy of the National Geophysical Data Center

Figure 12.10: *The 1960 Chile earthquake, which caused devastating damage, was estimated to be a 9.5 magnitude on the Richter scale*

Energy and the Richter Scale

Each higher value on the Richter scale represents a ten times increase in wave amplitude. However, in terms of energy, each higher number represents the release of about 31 times more energy!

The Moment Magnitude scale

The **Moment Magnitude scale** rates the total energy released by an earthquake. The numbers on this scale combine energy ratings and descriptions of rock movements. This scale can be used at locations that are close to and far away from an epicenter. The Richter and Moment Magnitude scales are similar up to magnitude 5. However, seismologists tend to use the more descriptive Moment Magnitude scale for larger earthquakes.

Measuring earthquake damage

The **Modified Mercalli scale** has 12 descriptive categories. Each category is a rating of the damage experienced by buildings, the ground, and people. Because earthquake damage can be different from place to place, a single earthquake may have different Mercalli numbers in different locations (Figure 12.11).

Category	Effects	Richter scale (approximate)
I. Instrumental	Not felt	1-2
II. Just perceptible	Felt by only a few people, especially on upper floors of tall buildings	3
III. Slight	Felt by people lying down, seated on a hard surface, or in the upper stories of tall buildings	3.5
IV. Perceptible	Felt indoors by many, by few outside; dishes and windows rattle.	4
V. Rather strong	Generally felt by everyone; sleeping people may be awakened	4.5
VI. Strong	Trees sway, chandeliers swing, bells ring, some damage from falling objects	5
VII. Very strong	General alarm; walls and plaster crack	5.5
VIII. Destructive	Felt in moving vehicles; chimneys collapse; poorly constructed buildings seriously damaged	6
IX. Ruinous	Some houses collapse; pipes break	6.5

X. Disastrous	Obvious ground cracks; railroad tracks bent; some landslides on steep hillsides	7
XI. Very disastrous	Few buildings survive; bridges damaged or destroyed; all services interrupted (electrical, water, sewage, railroad); severe landslides	7.5
XII. Catastrophic	Total destruction; objects thrown into the air; river courses and topography altered	8

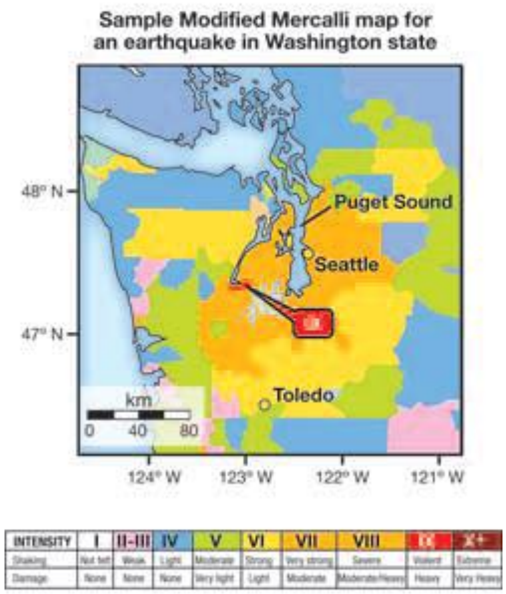


Figure 12.11: *From the map, youcan see that the earthquake was a category IX on the Modified Mercalli scale in a very small area. Most of the surrounding areas experienced less shaking and damage.*

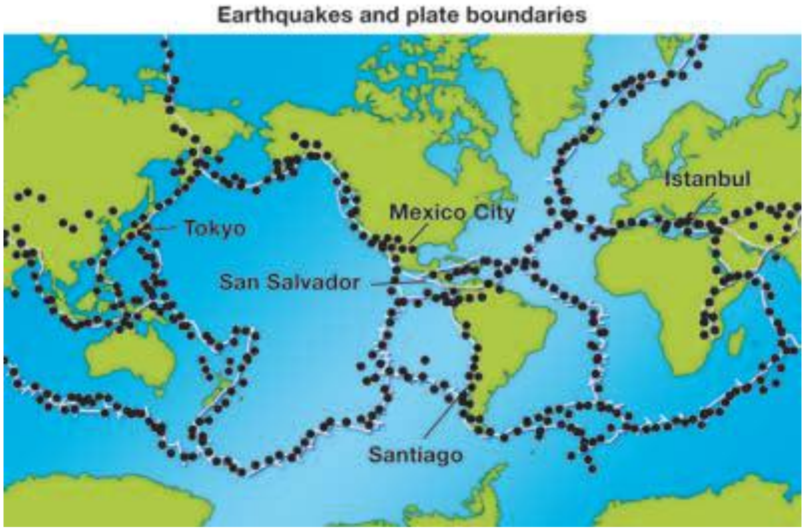
Earthquakes and plate boundaries

Boundaries of plates

When earthquake locations are plotted for many years, a map like the one below (at the lower left) can be created. Earthquakes commonly occur at the boundaries of lithospheric plates. They occur less commonly at faults that are inside plate boundaries. Note that in Figure 12.12, the earthquakes along the converging plates do not form a neat line. This is because plate boundaries tend to be *zones* of seismic activity. In particular, faults at transform fault boundaries, like the San Andreas Fault in Figure 12.13, have many branches. These fault branches form an *earthquake zone.*

Earthquakes along a transform fault boundary

The San Andreas Fault lies along the California coast (Figure 12.13). This famous fault passes right through San Francisco and part of Los Angeles. San Francisco has experienced several severe earthquakes and many smaller ones. The earthquake of 1906, together with the fires that it caused, destroyed much of the city. The damage caused by the earthquake was probably 8 or 9 on the Mercalli scale. Future earthquakes are expected here because the fault that lies under the city is still active.



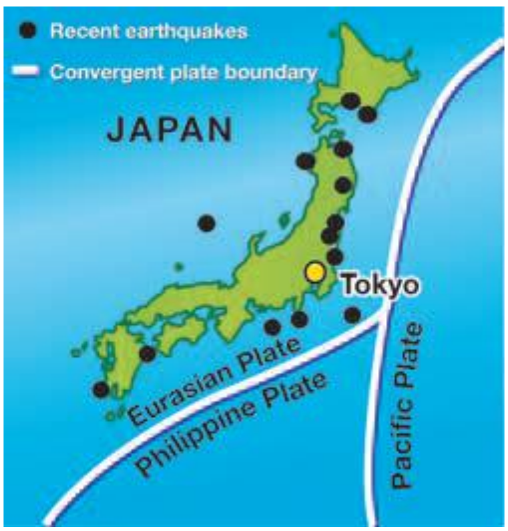


Figure 12.12: *Earthquakes along converging plate boundaries do not occur in neat lines, but occur in zones of seismic activity.*

Figure 12.13: *The San Andreas Fault lies along the California coast.*

12.1 Section Review

1. Put these events in order and then describe each: aftershock, foreshock, and earthquake.

2. What is the difference between the focus and the epicenter of an earthquake?

3. What three conditions are needed for stick-slip motion?

4. How is a lithospheric plate like a line of moving grocery carts?

5. How can one earthquake cause another earthquake?

6. What is the difference between body waves and surface waves?

7. List what can happen to a seismic wave as it moves from one material to another.

8. What is measured to determine the location of an epicenter?

9. At least how many seismic stations are needed to find the epicenter of an earthquake?

10. Are earthquakes the only source of seismic waves? Explain your answer.

11. How many times stronger is a 3.0 magnitude earthquake compared to a 2.0 magnitude earthquake on the Richter scale?

12. A friend tells you he witnessed books and other objects falling off his bookcase during an earthquake. What was the magnitude of this earthquake:
a. on the Modified Mercalli scale?
b. on the Richter scale?

13. The largest earthquake ever recorded occurred in Chile, which is on the west coast of South America. Why are earthquakes to be expected in Chile? Explain your answer.

14. Why is it possible for a single earthquake to have different Modified Mercalli scale ratings in different locations?