Earth's Dynamic Crust and Interior

TOPIC 12

How Scientists Study Earth's Dynamic Crust and Interior

Is there continental drift?

Well, yes and no. During the early 1900s, some geologists believed in an idea called continental drift, which Alfred Wegener developed into a fleshed-out hypothesis that described evidence to show that continents have changed locations over time. But he could not figure out how this happened. In the mid-1900s, scientists began studying the ocean floor, finding new data that led to the modern theory of plate tectonics. This theory describes how continents move, but as part of larger plates. Hence, there is "plate drift," not continental drift.

TOPIC 12

Earth's Dynamic Crust and Interior

Vocabulary

asthenosphere
continental crust
convergent plate boundary
crust
divergent plate boundary
earthquake
epicenter
faulted
folded
hot spot
inner core
island arc
lithosphere
lithospheric plate
mantle
mid-ocean ridge
Moho
oceanic crust
ocean trench
original horizontality
outer core
plate
plate tectonic theory
P-waves
seismic wave
subduction
S-waves
tectonic plate
transform plate boundary
tsunami
uplifted
volcanic eruption
volcano
young mountains

Topic Overview

Much evidence, such as volcanoes and earthquakes, indicates that Earth's crust is constantly undergoing change. You know that the crust moves because you have witnessed or read about earthquakes and the eruption of volcanoes. You also may have heard about measurements that indicate that mountains are "growing" and that the landmasses are changing their positions on Earth's surface.

Evidence of past movements of the crust is more indirect. Scientists must "read" the characteristics of rocks to learn about these past events. Thus, scientists have learned to understand Earth's lithosphere, surface features, and plate movements as well as the properties of Earth's interior. The **lithosphere** is the layer of rock that forms the outer shell at the top of Earth's interior. Earth's **crust** is the upper portion of the lithosphere. Note that whatever is stated in this chapter about the crust usually applies to the lithosphere as well.

Small Scale Crustal Changes

Much of the evidence for past movements of the crust is based on the concept of **original horizontality.** This concept assumes that sedimentary rocks and some extrusive igneous rocks, such as lava flows, form in horizontal layers parallel to Earth's surface. The layers of sedimentary rocks and extrusive igneous rocks are called strata or beds. Therefore, most strata found in positions other than horizontal are thought to have been deformed by crustal movement. (See Figure 12-1.)

Rock layers (strata) that no longer show their original horizontality are called deformed layers. Some of the types of deformed layers are folded, tilted, and faulted. **Folded** rock layers are bent or curved. Tilted rock layers are slanted or tipped. **Faulted** rock layers are offset or displaced along a type of crack called a fault. A fault is a crack in a mass of rock or soil along which there has been displacement, shifting, or movement of the rock or soil layers on each side of the crack.

Displaced marine (ocean) rocks as well as rocks with fossils are often found in sedimentary rock hundreds or thousands of meters above sea level. A fossil is any evidence of former life. These displaced rocks and fossils indicate that the land has been raised up, or **uplifted,** to its present position. A lowering of sea level could not have changed the location of the fossils because it is believed that sea level has only ever varied a few hundred meters. On the other hand, fossils from shallow water and from land have been found many hundreds of meters below sea level, which indicates a sinking or lowering of part of Earth's crust.

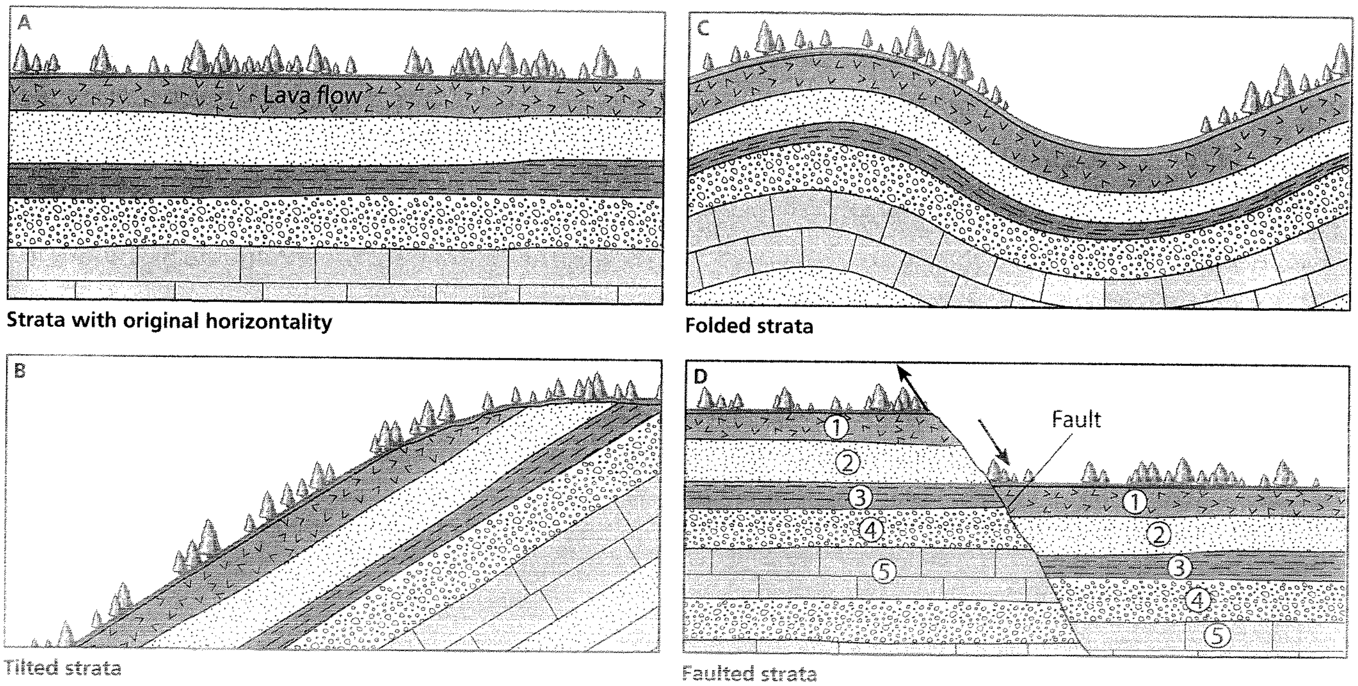


Figure 12-1. Strata, illustrating original horizontality and three types of deformed strata: The numbers in diagram D indicate strata that were originally continuous. The arrows show the direction of relative movement along the fault.

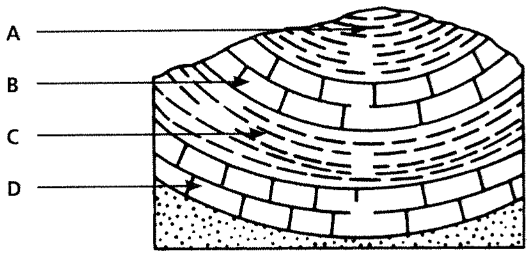
Review Questions

1. Draw a diagram of folded strata. Explain a geological event that might account for this deformation.

2. While hiking with a friend in New York State, you discover marine fossils in sedimentary strata at high elevations. What is the most logical explanation for their presence?

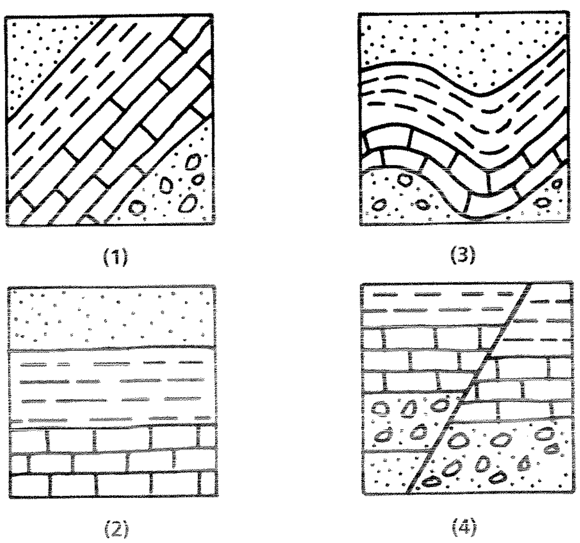
3. A line of former beaches along a coast, all 50 meters above sea level, is evidence of
(1) present erosion
(2) the present melting of polar ice caps
(3) land uplift
(4) a decrease in the deposition of marine fossils

4. The following diagram represents a vertical cross section of sedimentary rock layers that have not been overturned. Which principle best supports the conclusion that these layers have undergone extensive movement since deposition?

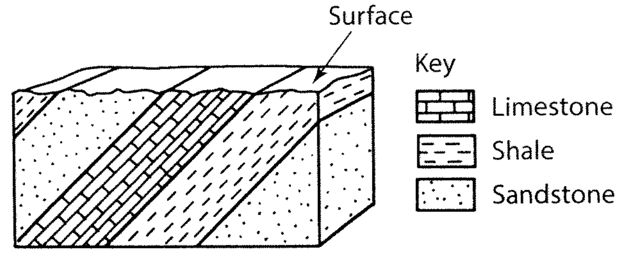


(1) Sediments are deposited with the youngest layers on top.
(2) Sediments are deposited in horizontal layers.
(3) Rock layers are older than igneous intrusions.
(4) Sediments containing the remains of marine fossils are deposited above sea level.

5. The following diagrams show cross sections of exposed bedrock. Which cross section shows the least evidence of crustal movement?



6. The following diagram represents a cross section of a portion of Earth's crust. What do these tilted rock layers suggest?



(1) This area remained fairly stable since the sediments were deposited.
(2) The sediments were deposited at steep angles and then became rock.
(3) Metamorphism followed the deposition of the sediments.
(4) Crustal movement occurred sometime after the sediments were deposited.

7. Recent measurements of elevation in New York State indicate that the land is slowly rising in the Adirondack Mountain region. Which statement best explains this change?
(1) The Adirondack Mountains are in a region of crustal uplift.
(2) The Adirondack Mountains are in a zone of few earthquakes.
(3) The rocks in the Adirondack Mountains are younger than those in other regions of New York.
(4) The gravitational attraction of the moon is greater in the higher Adirondack region.

8. Shallow-water fossils are found in rock layers deep beneath the ocean floor. This suggests that
(1) shallow-water organisms always migrate to deeper water to die
(2) parts of the ocean floor have been uplifted
(3) parts of the ocean floor have sunk
(4) the surface water cooled off, killing the organisms

Earthquakes and Igneous Activity, Including Volcanoes

An **earthquake** is a natural rapid shaking of the lithosphere caused by the release of energy stored in rocks. Most earthquakes are caused by the movement along faults, or faulting. Some earthquakes are associated with the movements of magma within the lithosphere and with volcanic eruptions. During an earthquake the potential energy stored in the rocks is given off as **seismic waves,** or earthquake waves. As shown in Figure 12-2, the earthquake starts at the focus, from which the waves are emitted. The location on Earth's land or water surface directly above the focus is called the **epicenter.** You often see epicenters plotted on maps of Earth's surface.

Scientists measure and record earthquake waves by using a seismograph—an instrument that shows how Earth shakes from the seismic waves. A seismograph records (on paper or another medium) "wiggles"—amplitudes of the wave—that represent Earth's shakings. The recording is called a seismogram. (See Figure 12-3.)

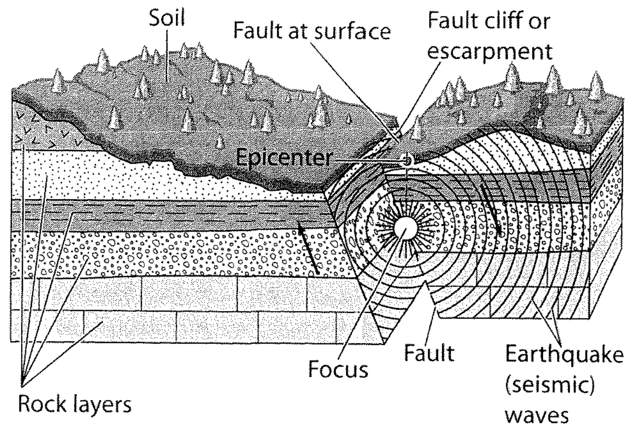


Figure 12-2. Terminology of an earthquake: Note the displacement of the rock layers along the fault. Also note that the epicenter is on Earth's surface directly above the focus.

Earthquake Waves

Seismic waves can be grouped into three categories—P-waves, S-waves, and surface waves. **P-waves,** also called primary waves, cause the particles they travel through to vibrate in the direction the waves are moving. The slower **S-waves,** also called secondary waves, cause the particles they travel through to vibrate at right angles to the direction the waves are moving.

The surface waves are produced when a P-wave or S-wave comes to Earth's surface. These waves only travel around Earth's solid surface and cause much of the surface shaking and damage of an earthquake.

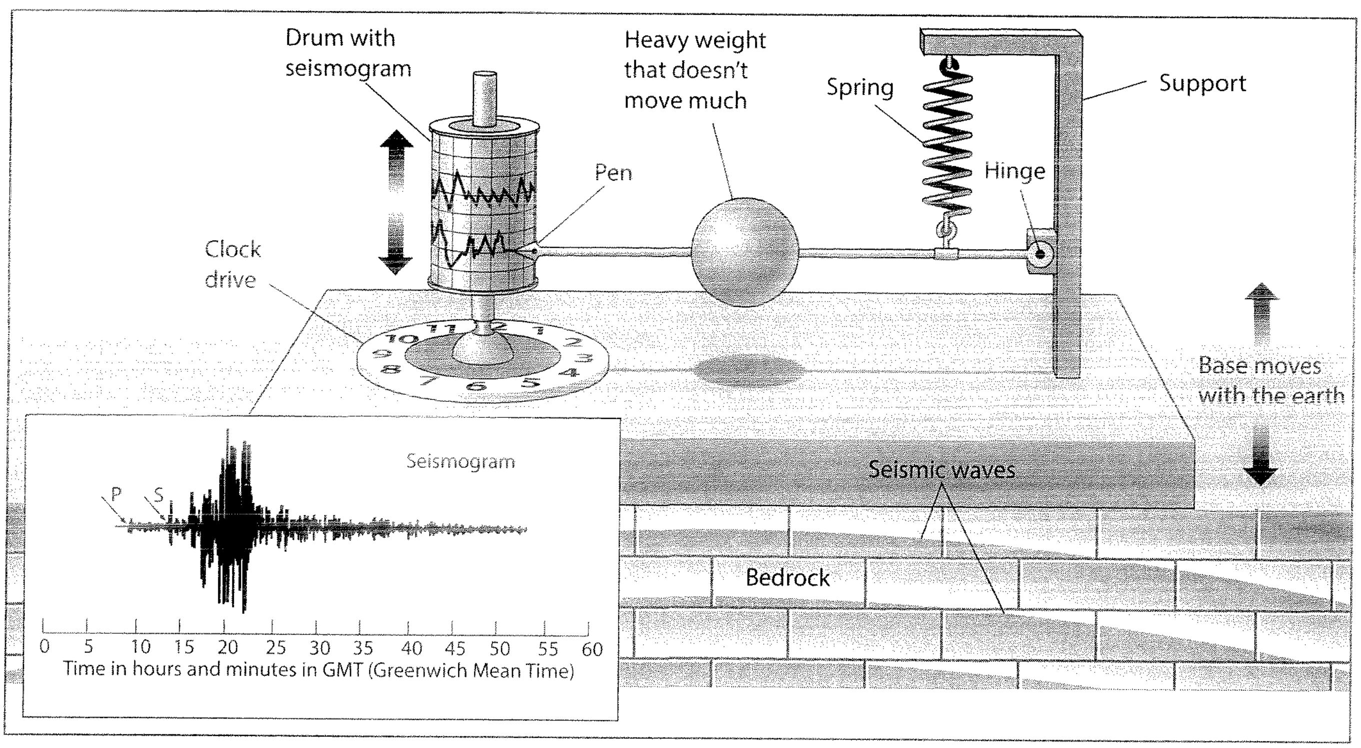


Figure 12-3. A simple seismograph and a seismogram: As Earth shakes during an earthquake, most of the seismograph moves up and down. Since the heavy weight resists movement because of momentum, the attached pen "writes" wiggles on a seismogram (shown in the insert). This seismogram has the record of the arrival times of P-waves (P) and S-waves (S) from an earthquake. P-waves arrive first because they are fastest.

Properties of Earthquake Waves The different types of seismic waves have different properties depending on the materials they pass through:

- In any one material, P-waves travel faster than all other types of seismic waves. S-waves are the second fastest. When an earthquake occurs, the P-waves will reach a seismograph before the S-waves do. (See Figures 12-3 and 12-4.)
- The velocity of seismic waves in Earth depends on the properties of the materials they are passing through. Generally, the more dense and rigid a material is, the greater the velocity of the waves. As seismic waves pass from a material of one density to a material of higher or lower density, the waves are refracted, or bent.
- Within the same material, an increase in pressure increases the velocity of the seismic waves.
- P-waves will pass through solids, liquids, and gases. S-waves will only pass through solids.
- Some P-waves and S-waves are reflected by, or bounce off, dense rock layers within Earth. This property is often used to locate valuable rock and mineral resources within Earth.

Location of an Epicenter Epicenters are located by using the velocity differences between the P-waves and S-waves. Since P-waves move faster than S-waves, the farther an observer is from an epicenter, the larger the time interval between the arrival of the P-waves and S-waves. The distance to the epicenter is determined by comparing the interval with the graph data. In Figure 12-4 for example, if the observer is 1000 kilometers from the epicenter, the P-waves arrive 2 minutes after the earthquake occurs and the S-waves arrive 4 minutes after the occurrence. There is thus a 2-minute interval between observation of the P-waves and observation of the S-waves. At 4000 kilometers from the epicenter, it takes 7 minutes for the P-waves to arrive and $12\frac{1}{2}$ minutes for the S-waves; the time interval between them is thus $5\frac{1}{2}$ minutes. The graph can be used to find the distance from the epicenter if the time interval between the arrival of the two waves is known. A similar diagram can be found in the *Earth Science Reference Tables.* (R)

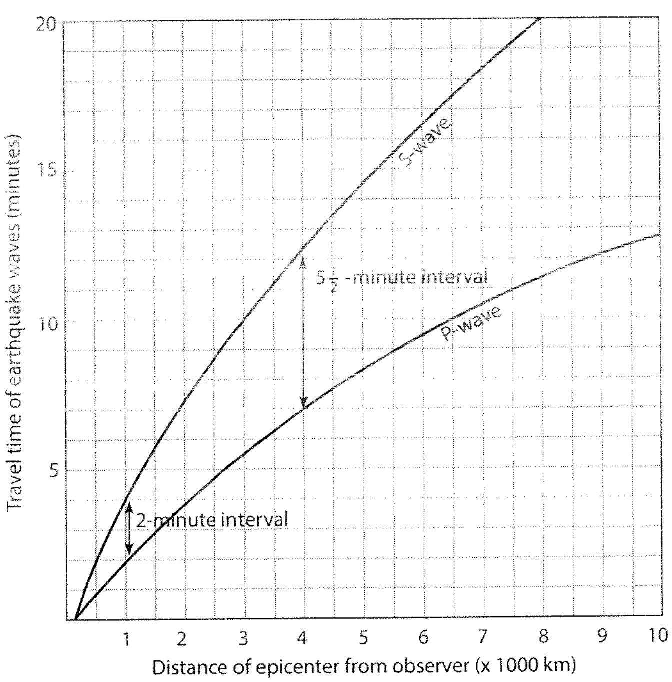


Figure 12-4. Travel times of P-waves and S-waves: The two curves in this graph show the time required for P-waves and S-waves to travel a given distance from the epicenter of an earthquake. Since the S-waves travel more slowly than the P-waves, the S-waves take longer to reach an observer.

To find the position of the epicenter, at least three seismograph locations must be used, and the epicenter distance must be calculated for each. For each of the three locations, the epicenter distance is then used as a radius, and circles are drawn on a globe or a map, as shown for locations A, B, and C in Figure 12-5. The place where all three circles intersect is the epicenter of the earthquake. Observations at one seismograph location provides only the distance to the epicenter, not the location or direction.

Finding the Origin Time of Earthquakes The time an earthquake originated can be determined from the epicenter distance and seismic-wave travel time.

The farther an observer is from the epicenter, the longer it takes the seismic waves to travel to the observation point. For example, suppose the observer is 4000 kilometers from the epicenter. Figure 12-4 shows that it took the P-wave 7 minutes to arrive; thus the earthquake occurred 7 minutes earlier than the time at which the P-waves were observed on the seismograph. Try this example: If the S-wave first arrived at a station at 10 hr:12 min:30 sec and the seismograph is 5500 kilometers away from the epicenter, when did the earthquake occur?

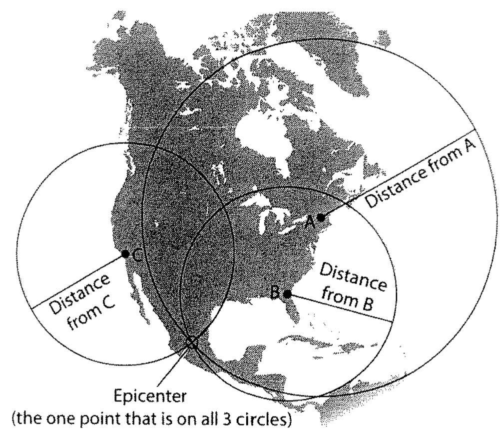


Figure 12-5. Locating the epicenter of an earthquake: Seismograph observations at three locations that are widely spaced are used. The distance to the epicenter is determined for each station, and a circle with this radius is then drawn around the station. The one point that lies on all three circles must be the epicenter.

Magnitude of Earthquakes The strength of an earthquake can be measured in various ways. An earthquake intensity scale can be used to measure the various effects of an earthquake on humans and the types of damage the event causes. Generally, the closer to the epicenter, the greater the damage; that is, the intensity for an earthquake varies with distance.

Scientists most often use an earthquake magnitude scale to measure the strength of earthquakes. Magnitude scales use the height of the wiggles on seismograms to help us infer the total amount of energy released by an earthquake.

The lowest value of magnitude is determined by the sensitivity of seismographs (less than 1), and the highest value (approximately 9.5) is determined by how much stress rocks can withstand before breaking. Figure 12-6 shows an example of one magnitude scale and the number of earthquakes that occur each year.

Earthquakes as a Natural Hazard

Earthquakes can cause great damage, injury, and death. What causes all the damage, death, and injuries during an earthquake? Earth doesn't

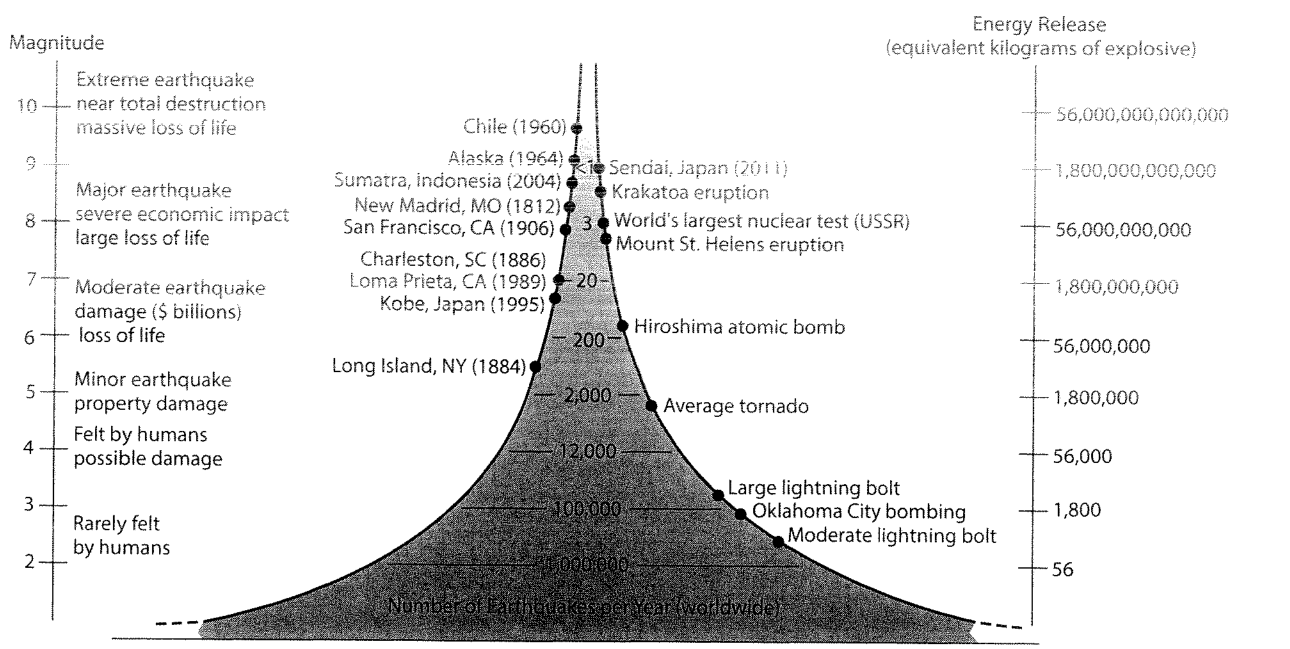


Figure 12-6. Earthquake magnitude scale: This scale provides one value for each earthquake that is an estimate of the total energy the event emits. Each whole-number value equals between 31 and 32 times more energy than the next lower number.

Digging Deeper

For many years, the Richter Scale was used, but the scale—named in 1935 after Charles F. Richter of the California Institute of Technology—was really only designed for small-to moderate-strength earthquakes in California and would not provide meaningful data for the strongest earthquakes. Most scientists now use a magnitude scale, which not only uses the height of the wiggles on the seismograms but also considers the length of the movement of the earthquake.

open up and "swallow" buildings and people; the shaking ground causes a series of events.

For example, shaking ground can cause a break in a railroad track, which in turn can cause a train wreck. If the train is carrying hazardous chemicals, they might spill, perhaps causing an explosion and a fire. Most injuries and fatalities are caused by parts of buildings falling on people and by the other related events.

Earthquake Prediction Scientists have been trying to successfully predict earthquakes for many years without a favorable outcome, except for long-term predictions. If we could predict earthquakes by a few weeks or even days, the population could then be evacuated. At present, the only reasonably good predictions have been general and long-term for a certain area. This type of prediction is possible because most earthquakes occur in specific zones. (See Figure 12-9.) Therefore, if enough earthquake history is known for a specific zone, then a reasonable prediction can be made.

Emergency Planning for Earthquakes Even though current methods of earthquake prediction are not of much value, the amount of damage, death, and injury from earthquakes can be greatly reduced with proper planning.

On an individual level, try to remember "drop, cover, and hold." Upon the first signs of shaking from what you believe to be an earthquake, don't go far, but drop down under a strong object (a strong desk or table, for example). Turn away from windows, and use one hand to cover your eyes. With the other hand, hold onto the strong object you are under. Do not try to run out of a building until the shaking is over. Most earthquakes last only 10 to 30 seconds, and it takes most of that time just to react.

Earthquake drills in the home, at work, and at school can help people to protect themselves, as can having emergency supplies at home, at work, in cars, and at school.

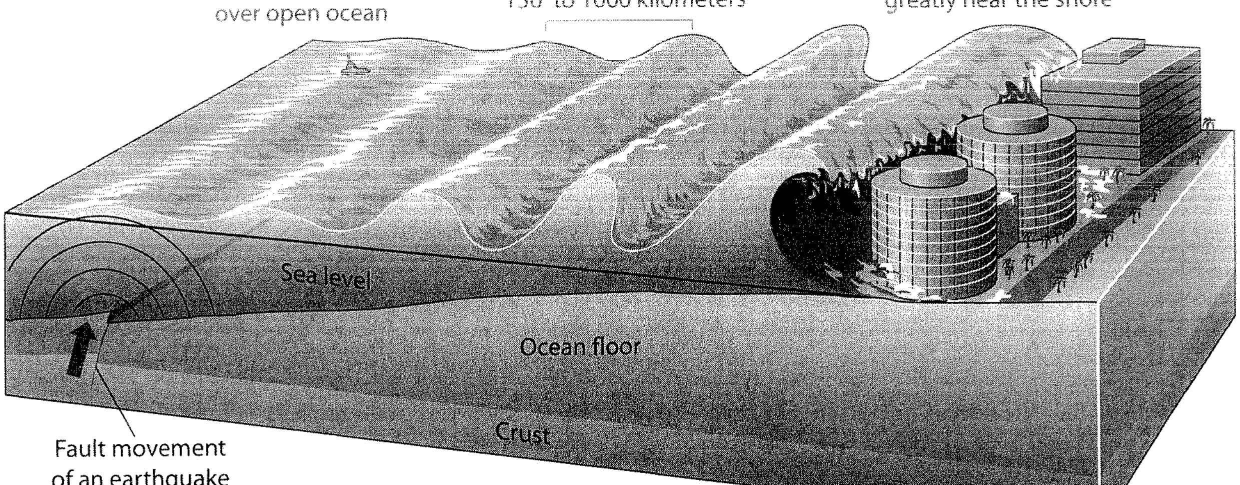


Figure 12-7. Tsunamis: These sometimes giant ocean waves can cause destruction similar to hurricane waves on shorelines. Tsunamis usually come as a series of waves from 10 to 60 minutes apart and may be over 30 meters high at shorelines.

On a community level, proper planning of building sites and proper building construction techniques can greatly reduce the chance of death and injury during an earthquake. An example of important planning includes inspecting the soil and bedrock to ensure that new buildings are constructed on solid ground. Another example of proper planning is retrofitting older buildings to make them safer, such as bolting buildings to their foundations and cross-bracing walls.

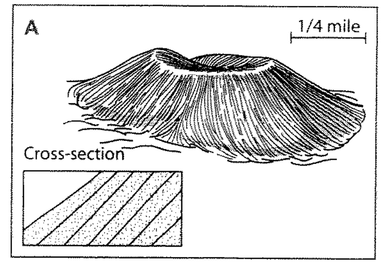
Tsunami

A special condition associated with strong earthquakes on the ocean floor is the production of seismic sea waves. **Tsunami**—the Japanese word for "wave in the harbor"—is a large wavelength ocean wave produced by disruption of the ocean floor. This disruption can be caused by the faulting associated with an earthquake (as shown in Figure 12-7), volcanic eruptions, meteorite impact or rapid landslide type of mass movement. The shoreline damage from a tsunami is much the same as that created by hurricane waves. In rare cases a tsunami can produce destructive coastal waves of more than 30 meters. Although sources vary, most agree that between 200,000 and 300,000 people died from the tsunami that resulted from the Sumatra, Indonesia, earthquake of 2004.

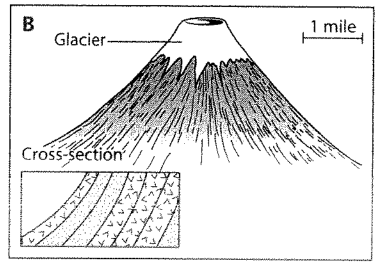
Igneous Activity and Volcanoes

Recall that igneous rocks and the features formed from them are of two types—intrusive and extrusive. Intrusions composed of intrusive (plutonic) igneous rock form when magma stays within the lithosphere. When magma reaches the surface, it becomes lava and forms masses—extrusions—composed of extrusive (volcanic) igneous rock. If the lava flows out of cracks and is very fluid, a feature called a "lava flow" forms. Successive lava flows can form large features like the Columbia Lava Plateau, which covers much of Oregon, Washington, and Idaho. (See Figure 12-8, diagram D.) If the lava forms a significant mound with a slope of at least a few degrees, then the mass is a volcano. A **volcano** is a mountain composed of extrusive igneous rocks. A **volcanic eruption** is the giving off of gases, lava, and/or lava rock onto Earth's surface or into the atmosphere through the opening or vent of a volcano. Volcanic eruptions range from a flow of lava down the side of a volcano to a massive explosion of gas, solid particles, and/or lava into the atmosphere similar to the Mount St. Helens eruption in Washington in 1980.

Volcanoes as a Natural Hazard Similar to earthquakes, volcanic eruptions can result in a multitude of events that damage, injure, and kill. People can be injured and killed by flowing lava, falling rock, and gases of over 1000°C. Farmland and buildings are often buried or burned by lava flows and volcanic ash during eruptions. The secondary events of a volcano are often more destructive. Volcanic ash often mixes with water from melted glaciers, causing massive mudslides and flooding. The gases emitted by a volcano,



Cinder cone–common in much of western USA and has mostly explosive eruptions

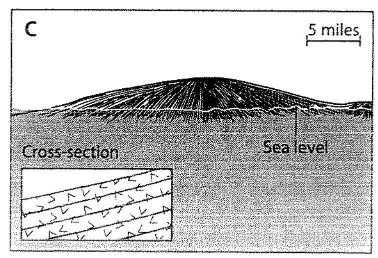


Composite volcano, such as Mount St. Helens in Cascades of western USA and has both explosive and quiet lava flow eruptions

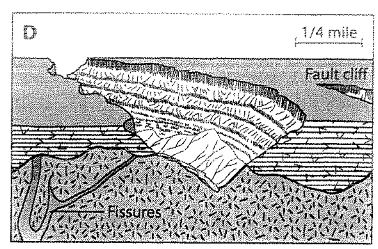
Key

Loose igneous rock fragments, such as ash from explosive eruptions

Lava rock from lava flows or quiet eruptions



Shield cone, such as the Hawaiian Islands and has mostly quiet lava flow eruptions



Lava plateaus

Figure 12-8. Volcanic mountains and plateaus: Volcanic mountains are composed of two types of igneous materials. One is lava rock formed from flows of liquid lava. The other is loose rock fragments—from ash to boulder size—formed by the exploding of lava and rock fragments into the air and their eventual settling to form a mountain. A volcanic plateau is relatively high landscape composed of horizontal layers of lava rock formed by many lava flows emitted from fissures (cracks) in the crust.

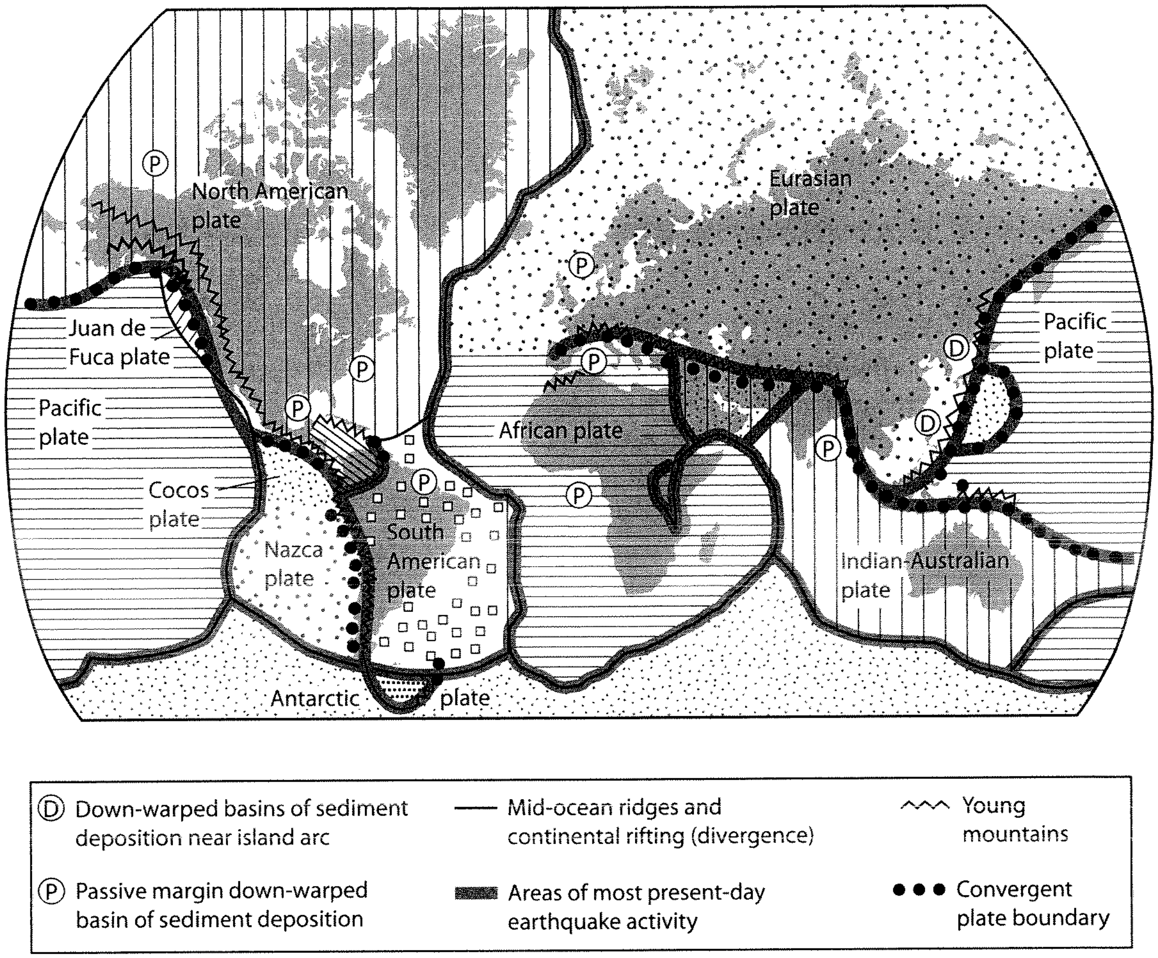


Figure 12-9. Zones of current crustal activity and Earth's major plates: Note that the borders of the plates are the locations of most current crustal activity, which includes volcanic eruptions and earthquakes. Most of the world's active volcanoes are located where mid-ocean ridges or young mountains are indicated on the map.

such as sulfur and chlorine compounds and carbon dioxide, can cause immediate death or long-term lung damage. In massive eruptions, volcanic ash is ejected into the stratosphere, where it has been known to cool Earth by blocking insolation reaching Earth's surface.

Prediction of Volcanic Eruptions There has been some success in predicting volcanic eruptions in sufficient time for people to escape from an area. Though most eruptions go unpredicted, some of the more dangerous volcanoes in populated regions are monitored by using a series of tools. Satellites measure infrared energy from the upper atmosphere and report on the increasing heat from rising magma. Tilt meters measure increasing slopes as the volcano inflates with magma. Elevation, benchmarks, latitude and longitude measurements, and topographic maps indicate the increases in elevation and width common before eruptions. When magma moves upward before volcanic eruptions, it pushes rock out of the way, causing hundreds of earthquakes. Using the three-seismograph method to determine epicenters, scientists can "watch" magma rise and can provide eruption predictions within an hour of an actual eruption. With predictions such as these, people have enough early warning to develop emergency action plans, including rescue routes.

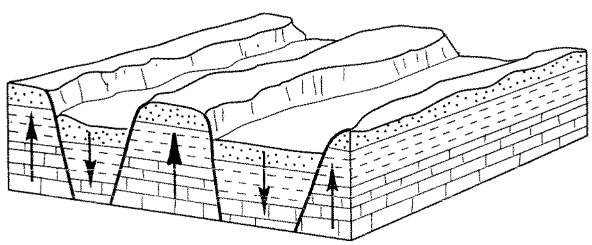
Zones of Crustal Activity

Zones of frequent crustal activity can be located on Earth's surface. Major areas of uplift, sinking, earthquakes, and volcanic eruptions are often found together and are associated with features like young continental mountains, ocean trenches, island arcs, and mid-ocean ridges (mountain ranges in ocean areas). Note that the regions surrounding the Pacific Ocean contain a majority of these related events and features, and are thus referred to as the "Ring of Fire." Many of these associations are illustrated in Figure 12-9. The fact that these activities and features are clustered hints at their common origins, which will be discussed later in this topic.

Review Questions

9. The landscape shown in the following diagram is an area of frequent earthquakes.

This landscape provides evidence for



(1) converging convection cells within the rocks of the mantle
(2) density differences in the rocks of the mantle
(3) movement and displacement of the rocks of the crust
(4) differential erosion of hard and soft rocks of the crust

10. Which statement about Earth's crust in New York State is best supported by the many faults found in the crust?

(1) The crust has moved in the geologic past.
(2) The crust has been inactive throughout the geologic past.
(3) New faults will probably not develop in the crust.
(4) An earthquake epicenter has not been located in the crust.

11. Recent volcanic activity in different parts of the world supports the inference that volcanoes are located mainly in

(1) the centers of landscape regions
(2) the central regions of the continents
(3) zones of crustal activity
(4) zones in late stages of erosion

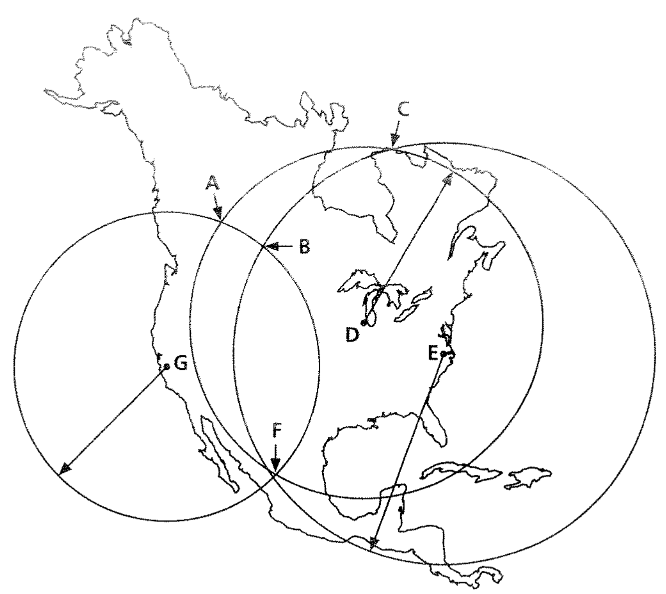
12. Where do most earthquakes originate?

(1) within Earth's outer core
(2) along specific belts within the crust
(3) randomly across the entire Earth's surface
(4) evenly spaced along the Moho interface

13. Earthquakes generate primary waves (P-waves) and secondary waves (S-waves). Compared to the speed of secondary waves in a given Earth material, the speed of primary waves is

(1) always slower
(2) always faster
(3) always the same
(4) sometimes faster and sometimes slower

The following diagram illustrates how the observatories in Pasadena, California; Chicago, Illinois; and Washington, D.C., locate the epicenter of an earthquake. Base your answers to questions 14 through 17 on the diagram.



14. The epicenter of the earthquake is located nearest

(1) A (2) B (3) C (4) F

15. The separation in time between the arrival of primary and secondary waves is

(1) greatest at station G (Pasadena)
(2) greatest at station D (Chicago)
(3) greatest at station E (Washington, D.C.)
(4) the same at all stations

16. If the method illustrated by the diagram is used to locate the epicenter of an earthquake, it appears unlikely for an individual observatory operating independently to determine the

(1) direction to the epicenter
(2) distance to the epicenter
(3) distance to an epicenter under the ocean
(4) interval between the initial and subsequent seismic waves

17. The time lapse between the arrival of the P-waves and S-waves on ONE recording of seismic waves can be used to determine the

(1) magnitude of the earthquake
(2) exact location of the focus
(3) exact location of the epicenter
(4) distance to the epicenter

---

18. You record evidence of an earthquake on your seismograph. What information about the earthquake's epicenter can be determined from your seismograph alone?

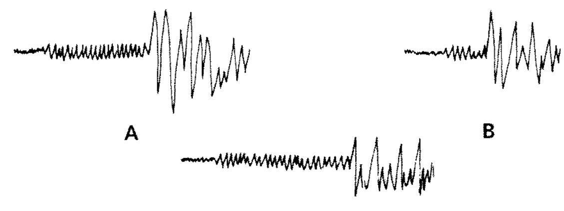
19. A seismic station is 2000 kilometers from an earthquake epicenter. According to the *Earth Science Reference Tables,* how long does it take an S-wave to travel from the epicenter to the station?

(1) 7 min 20 sec (3) 3 min 20 sec
(2) 5 min 10 sec (4) 4 min 10 sec

20. The occurrence of earthquakes along a fault in New York State is an example of a

(1) cyclic change that can be predicted
(2) cyclic change that cannot be predicted
(3) noncyclic change that is easy to predict
(4) noncyclic change that is difficult to predict

21. The following diagrams represent seismographic traces of three disturbances—A, B, and C—recorded by the same seismograph.



The traces indicate that the distance from the station to the epicenters of the three disturbances is

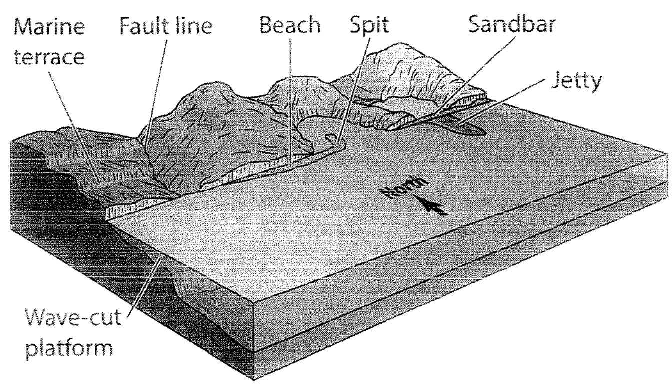
(1) least for disturbance A
(2) least for disturbance B
(3) least for disturbance C
(4) the same for all three disturbances

---

22. The diagram below represents a shoreline in New York State; several general features have been labeled.

Past movements along the fault line most likely caused the formation of

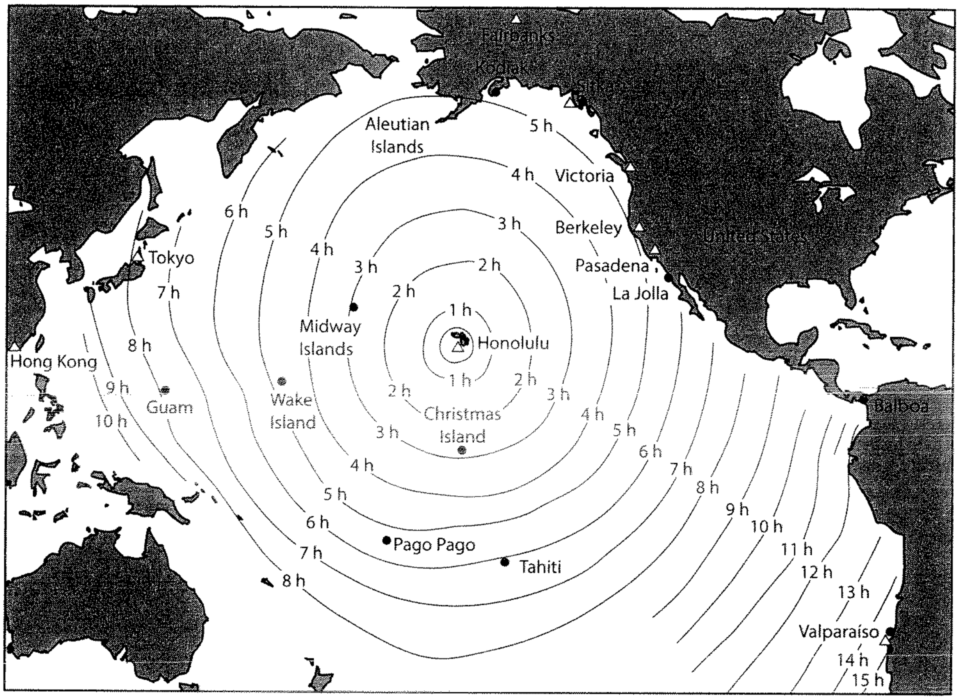
(1) the sandbar
(2) tsunami
(3) ocean currents along the shore
(4) tides



23. Which information would be most useful for predicting the occurrence of an earthquake at a particular location?

(1) elevation
(2) climate
(3) seismic history
(4) number of nearby seismic stations

Base your answers to questions 24 through 28 on the following map. The map shows the time of arrival of seismic sea waves (tsunamis) from locations throughout the Pacific Ocean to the Hawaiian Islands.
For example, an earthquake at any location on the line labeled "6 h" could produce a tsunami that would arrive in Honolulu 6 hours later.



Reporting Stations
- ● Tide stations
- △ Seismograph stations

0 500 1000 2000
Distance (miles)

h = hours

24. From which location would a tsunami arrive at Honolulu in the shortest time?

(1) Kodiak (3) Tahiti
(2) La Jolla (4) Wake Island

25. Which reporting station is NOT located on the Pacific plate?

(1) Hong Kong (3) Honolulu
(2) Midway (4) Tahiti

26. Approximately how fast do seismic sea waves travel from Midway to Honolulu, Hawaii?

(1) 31 to 51 mph (3) 1500 to 2000 mph
(2) 300 to 500 mph (4) 3000 to 5000 mph

27. The most likely reason for collecting this Pacific Ocean data is that Honolulu is

(1) the site of frequent major eruptions
(2) an equal distance from many seismic stations
(3) surrounded by earthquake-prone zones
(4) the site of a major tide station

28. Locations in this region where major earthquakes occur are most closely associated with areas of

(1) volcanic eruptions
(2) P-wave absorption
(3) magnetic field reversal
(4) mid-continental folding

A Model of Earth's Interior

Getting information about Earth's interior from direct observation is a difficult task. Therefore, most of its properties have been inferred from the study of earthquake waves.

Methods of Studying Earth's Interior

The deepest mines are little more than 3.5 kilometers deep, and the deepest drill hole (in Russia) is approximately 12 kilometers deep. This 12 kilometers represents less than 0.2 percent of the distance to the center of Earth.

Scientists infer most of the properties of Earth's interior through the study of seismic (earthquake) waves. This is much the same as studying human interiors with methods such as X-rays, ultrasounds, and CAT scans. By comparing thousands of seismograms from hundreds of locations, scientists have determined the times the different types of seismic waves arrive and when they don't arrive at numerous locations around Earth. By comparing these records with tests done using explosives in the oil industry and tests with nuclear bombs, scientists discovered that seismic waves refract, reflect, change velocity, and become absorbed by various parts of Earth's interior. Figures 12-10 and 12-11 show the most common model of Earth's interior that has resulted from these seismic wave studies.

Zones of Earth

Our analysis of seismic waves indicates that Earth is composed of a number of zones, as shown in Figures 12-10 and 12-11. The **crust** is the outermost part of Earth below the atmosphere or hydrosphere. Though mostly solid rock, the crust includes the soil and eroded and weathered rock deposits. Below the crust is the mostly solid part called the **mantle,** Earth's thickest zone that contains approximately 80 percent of Earth's volume. The mantle is separated from the crust by a thin interface called the **Moho.** Below the Moho, the rocks become denser. The whole crust and the very uppermost portion of the mantle (called the rigid mantle) are together called the **lithosphere.** (See Figure 12-11.) The lithosphere is

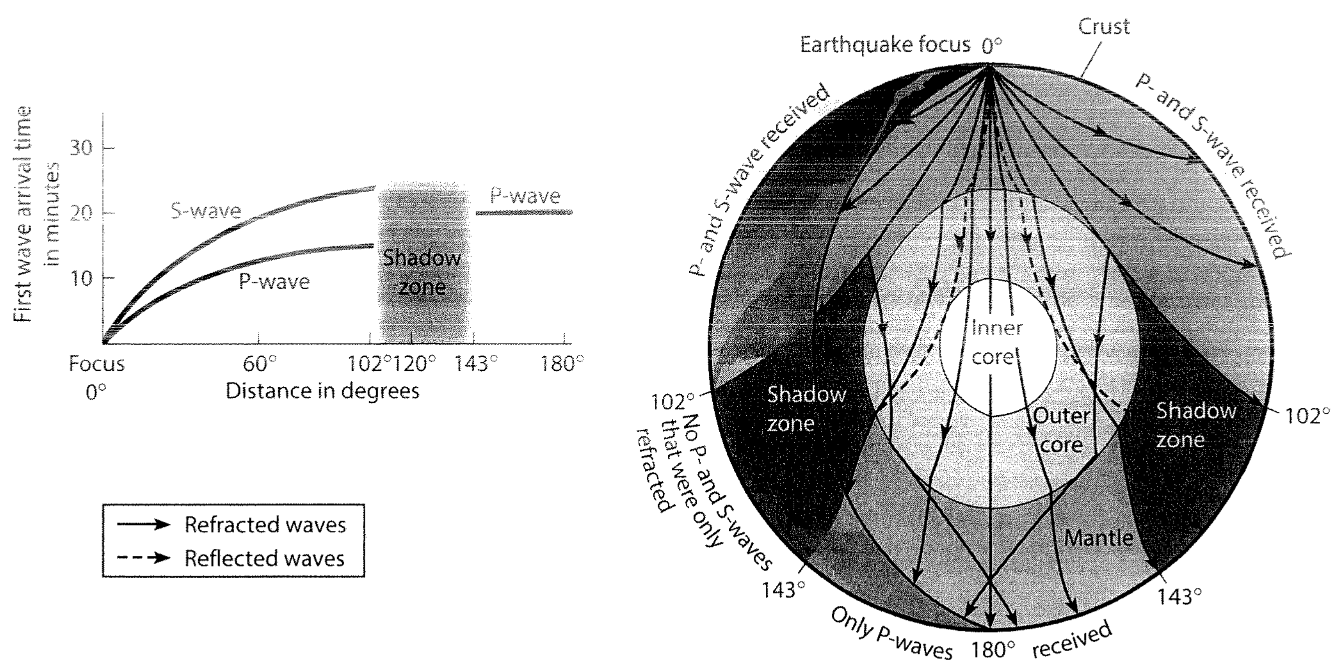


Figure 12-10. Arrival times and paths of seismic waves moving through Earth's interior: Analysis of the times seismic waves arrive has resulted in interpretations of reflections and refractions of these waves in Earth's interior. This analysis has resulted in the standard model of the zones of Earth's interior shown here.

divided into sections called "plates," which you will study in the next section.

Below the lithosphere is another portion of the upper mantle called the **asthenosphere.** This zone was discovered because it was found that seismic waves decreased in velocity from approximately 100 to 700 kilometers below Earth's surface. The asthenosphere is believed to be a plastic-like portion of the upper mantle that is at least partly molten. Much of the magma and lava of the crust and lithosphere is thought to originate in this zone. Note on the temperature graph in Figure 12-11 that the melting point and temperature curve intersect, indicating this partial melting. The asthenosphere allows the plates of the lithosphere to move around Earth's surface and to move up and down. Below the asthenosphere is the majority of the mantle, called the stiffer mantle.

Beneath the mantle Earth's core is divided into two parts—the **inner core** and the **outer core.** Figure 12-10 shows the outermost dimension—by area—of the shadow zone of the outer core that, due to refraction, does not receive any refracted seismic waves. The bottom of the outer core is indicated by the waves reflected off the outside edge of the inner core. Figure 12-10 also provides evidence that the outer core is liquid: Because no S-waves pass through the zone, it can't be a solid, and because the zone has too much pressure, it cannot be a gas. The S-waves are absorbed as they enter the outer core. The liquid nature of the outer core is also indicated by the major drop in P-wave velocity, as shown in Figure 12-11. Beneath the outer core is the inner core extending down to Earth's center. Due to the great pressures and the increase in P-wave velocity at the inner core (as shown in Figure 12-11), the inner core is believed to be a solid.

Earth's Crust Earth's crust, or upper lithosphere, is divided into two major divisions. The **continental crust** makes up the continents and larger islands, and the **oceanic crust** makes up most of the crust beneath the oceans. The continental crust is usually much thicker than the oceanic crust. The continental crust is thickest where highest—in mountain regions—and usually thinnest beneath coastal regions.

The two crusts are also distinguished by differences in composition and density.

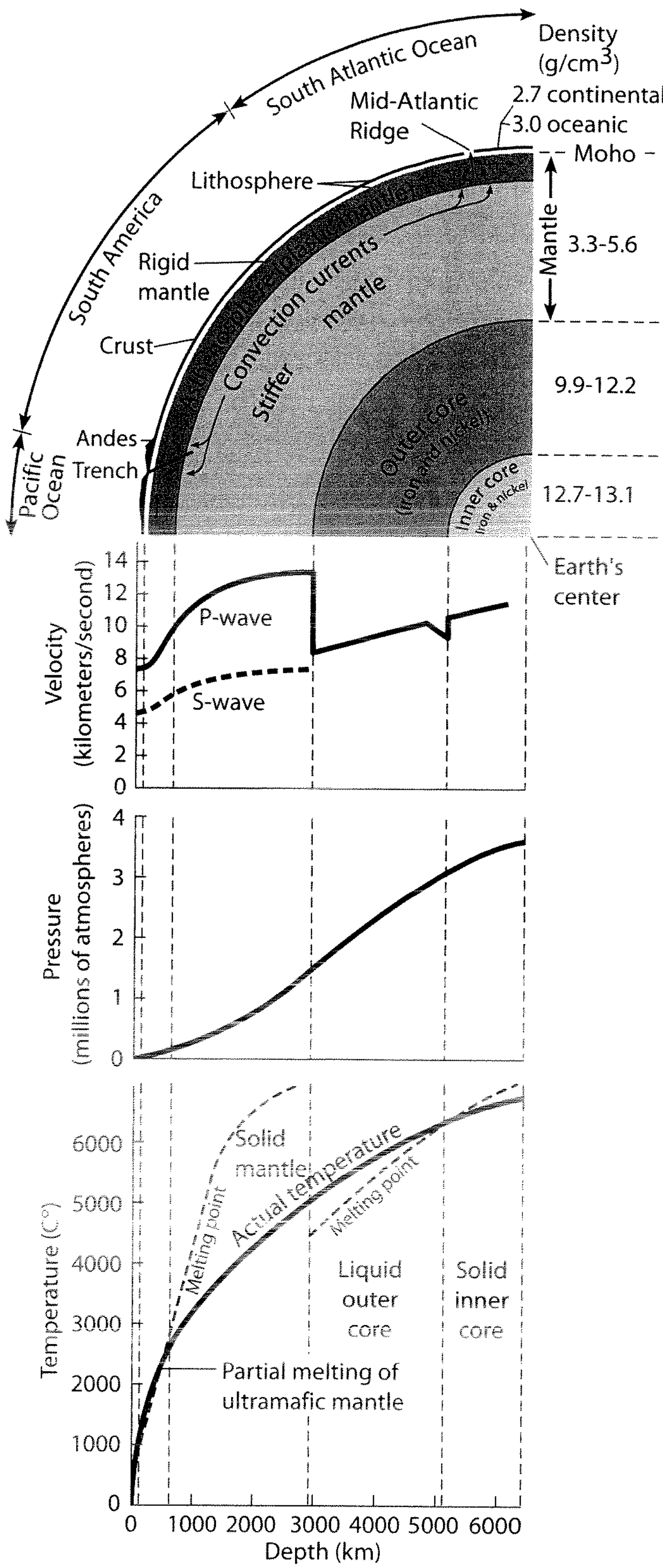


Figure 12-11. Properties and zones of Earth's interior: Analysis of the seismic waves and other studies have resulted in the inference about Earth's interior illustrated here. Note that most of Earth's interior is solid except for the outer core and portions of the asthenosphere, both of which are liquid. (See also the Inferred Properties of Earth's Interior in the *Earth Science Reference Tables.*)

The continental crust is made largely of granitic rocks—rocks with a mineral or chemical composition similar to granite. The oceanic crust is composed mostly of basaltic rocks—rocks similar in mineral or chemical composition to basalt. The granite is less dense than the basalt; thus, the granitic continental crust is less dense than the basaltic oceanic crust. See the average value of the density of the continental crust and oceanic crust (R) on the Inferred Properties of Earth's Interior in the *Earth Science Reference Tables.*

Composition of Earth's Interior Many scientists think Earth's inner and outer core are composed largely of iron and nickel. There is much evidence to support this hypothesis, including the iron and nickel composition of many meteorites and Earth's magnetism—iron and nickel are two of a few magnetic elements. In addition, a combination of iron and nickel at the temperatures and pressures believed to be in Earth's core can account for the observed properties of the seismic waves that pass through the core.

The high-density iron-nickel composition of the core and the low-density composition of the crust indicate that the mantle must have a composition different from the crust and the core and an intermediate density.

Earth's crust is composed mostly of rocks and minerals, as illustrated on (R) the various charts in the *Earth Science Reference Tables* depicting minerals, sedimentary rocks, metamorphic rocks, and igneous rocks. Generally, the crust is composed of low-density rocks with a mixture of granitic and basaltic compositions.

Review Questions

29. In developing a model of Earth's deep interior, most of the evidence was derived from

(1) deep wells
(2) mining operations
(3) observation of other planets
(4) seismic data

30. Through which zones of Earth do primary waves (P-waves) travel?

(1) only the crust and mantle
(2) only the mantle and outer core
(3) only the outer and inner core
(4) the crust, mantle, outer core, and inner core

31. According to the *Earth Science Reference Tables,* in which group are the zones of Earth's interior correctly arranged in order of increasing average density?

(1) crust, mantle, outer core, inner core
(2) crust, mantle, inner core, outer core
(3) inner core, outer core, mantle, crust
(4) outer core, inner core, mantle, crust

32. What evidence has been obtained concerning the existence of the Moho and Earth's mantle?

(1) satellite images
(2) well drillings
(3) exposures in deep canyons like the Grand Canyon
(4) refraction of earthquake waves

33. What is the relationship among density, temperature, and pressure inside Earth?

(1) As depth increases, density, temperature, and pressure decrease.
(2) As depth increases, density and temperature increase, but pressure decreases.
(3) As depth increases, density increases, but temperature and pressure decrease.
(4) As depth increases, density, temperature, and pressure increase.

34. In which parts of Earth's interior would melted or partially melted material be found?

(1) stiffer mantle and inner core
(2) stiffer mantle and outer core
(3) crust and inner core
(4) asthenosphere and outer core

35. An earthquake occurs in city A. Recordings on a seismograph in city B show only the presence of P-waves. City A and B are on opposite sides of Earth—180° apart. What does this information allow you to infer about the structure of Earth's interior?

36. How does the composition of the oceanic crust compare with the composition of the continental crust?

(1) The oceanic crust is mainly limestone, while the continental crust is mainly sandstone.
(2) The oceanic crust is mainly limestone, while the continental crust is mainly granitic.
(3) The oceanic crust is mainly basaltic, while the continental crust is mainly sandstone.
(4) The oceanic crust is mainly basaltic, while the continental crust is mainly granitic.

37. As one travels from an ocean shore to the interior of a continent, the thickness of Earth's crust generally

(1) decreases
(2) increases
(3) remains the same

38. How does thickness and density of the continental crust compare to that of the oceanic crust?

(1) The continental crust is thicker and less dense than the oceanic crust.
(2) The continental crust is thicker and denser than the oceanic crust.
(3) The continental crust is thinner and less dense than the oceanic crust.
(4) The continental crust is thinner and denser than the oceanic crust.

39. The overall density of Earth is approximately 5.5 g/cm^3. The average density of Earth's crust is between 2.5 g/cm^3 and 3.0 g/cm^3. What does this suggest about the density of Earth's core?

40. The composition of some meteorites supports the inference that Earth's core is composed of

(1) aluminum and calcium
(2) iron and nickel
(3) silicon and oxygen
(4) magnesium and potassium

41. The temperature of rock located 1000 kilometers below Earth's surface is approximately

(1) 1000°C
(2) 2600°C
(3) 3300°C
(4) 4300°C

Plate Tectonics

People have always wondered about the origin of continents, mountain ranges, volcanoes, earthquakes, and the multitudes of other features and events. In the past, many legends, religious beliefs, and scientific theories have tried to explain Earth's features and events. Some of the older scientific theories include cooling and contraction of Earth, expansion of Earth, and continental drift. None of these earlier theories seems satisfactory for most of the scientific community today. Since the 1960s many new discoveries from the studies of ocean drilling, Earth's magnetism, satellite observations, and detailed analysis of rocks and fossils have led to the plate tectonic theory. This theory has done for the earth sciences what evolution and genetics have done for the biological sciences. It has provided a unifying model to explain most, if not all, major features and events of Earth's lithosphere.

The Plate Tectonic Theory

The basic concept of the **plate tectonic theory** is that Earth's lithosphere is broken up into sections or pieces called **plates**—also called **lithospheric plates** and **tectonic plates**—and their movement and interaction produce major changes in Earth's surface. In this book the term "plates" will mostly be used.

These plates move about Earth's surface at a rate of a few centimeters per year (approximately the rate of fingernail growth). These plates can also move up and down—usually at rates of only millimeters per year—due to uplifting and sinking. The plates can move around and up and down because they are floating on the asthenosphere—a plastic-like layer of the mantle.

Digging Deeper

It should be understood that the continents don't drift or move on their own; they move as their associated plates move. Continental drift was a term used before common acceptance of plate tectonic theory. Continental drift means the continents by themselves are moving around Earth's solid surface. Figure 12-12 and the Inferred Position of Earth's Landmasses section of Geologic History of New York State in the *Earth Science Reference Tables* both show that the continents have drifted, but actually the continents only move as the plates move.

Refer to Figure 12-12 and the Tectonic Plates map in the *Earth Science Reference Tables* to become familiar with the names and locations of the various plates. You will observe that the plates usually don't follow continent or ocean boundaries. Note that the North American plate includes parts of Asia and North America; the Pacific, Arctic, and the Atlantic Oceans; and Greenland and part of Iceland. Westernmost California and Mexico are part of the Pacific plate. Most plates have continental and oceanic crust at their tops. A small number of plates are oceanic—that is, they have only oceanic crust at their tops, like the Nazca and Philippine plates.

At least three times, if not more, most of the large landmasses (continents and larger islands) have come together, forming supercontinents. Figure 12-12 shows how the supercontinent Rodinia formed approximately 800 million years ago and how the continents have split and formed since then. Note that diagrams G and H indicate the projected positions of landmasses in the future, based on the rates and directions the plates are moving in now.

The Three Types of Plate Boundaries

As the plates move, they interact in three ways—they can separate, collide, and slide by each other. Most of the major events involving Earth's crust—such as mountain building, earthquakes, and volcanic eruptions—occur at the boundaries where the plates interact. Each of the three types of plate boundaries has its own set of unique events and features, which are illustrated in Figure 12-13.

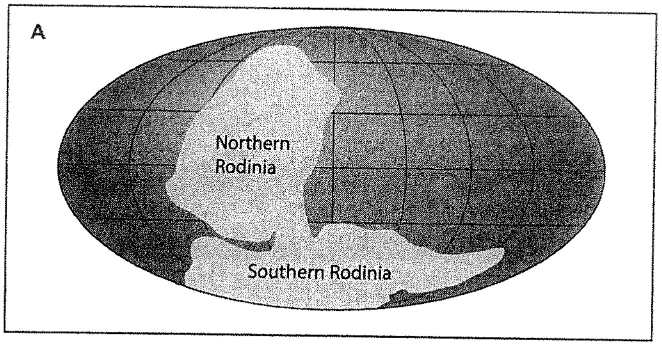
Divergent Plate Boundaries Where two plates separate, or diverge, the boundary is called a **divergent plate boundary.** At these locations the plates move apart and magma rises from below to fill in the separation, resulting in igneous intrusions and extrusions, such as lava flows and volcanoes. (See Figure 12-13B.) This divergence is sometimes called sea-floor spreading.

This magma and resulting lava form igneous rock that creates new crust and lithosphere, which are then split and divided in two by the divergence. The magma that forms in these regions is the result of divergence that lowers the confining pressure and melts rocks of the lower lithosphere and asthenosphere. The divergence also results in many earthquakes, most of which are shallow in depth. If the divergence is within the continental crust, the result is a continental rift valley of mountains created by faulting and much volcanic activity. (See Figure 12-13A.)

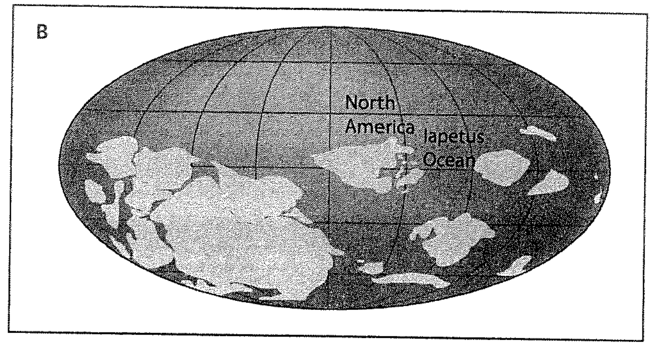
When the divergence is within oceanic crust, the faulting and volcanic activity result in a **mid-ocean ridge,** a basaltic mountain range at the bottom of the ocean that is composed mostly of volcanoes and lava flows. The mid-ocean ridges often have a central depression, or rift valley, as shown in Figure 12-13B.

Convergent Plate Boundaries When two plates collide, or converge, the result is a **convergent plate boundary.** Much of the dramatic events and features of Earth's crust are created at these convergent boundaries. There are three varieties of convergent plate boundaries:

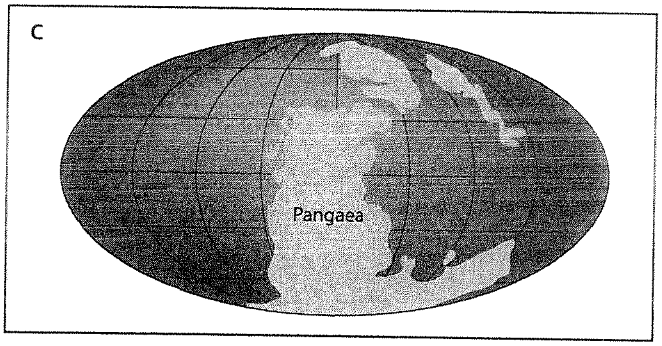
- both plates with oceanic crust on top



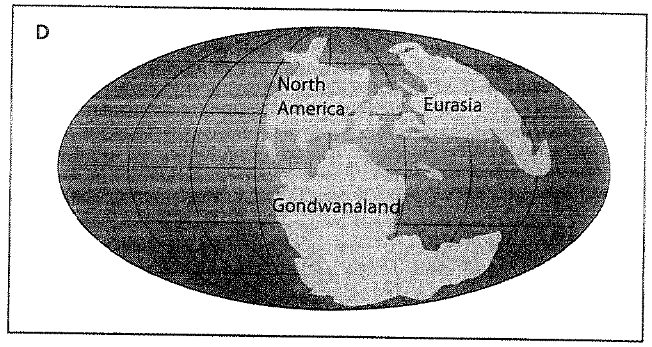
Earth around 700 millions years ago as supercontinent Rodinia is breaking up.



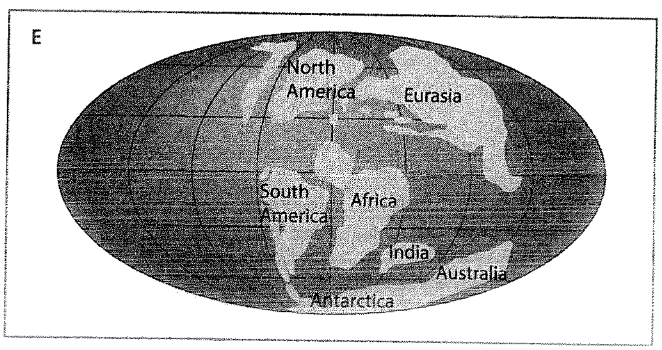
Earth around 550 million years after the break up of a supercontinent.



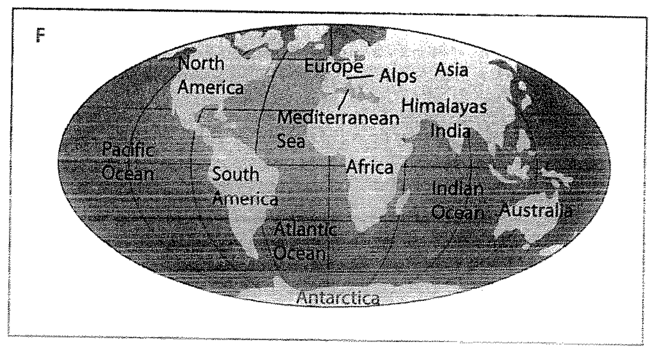
Earth around 250 million years ago when supercontinent Pangaea is just beginning to break up.



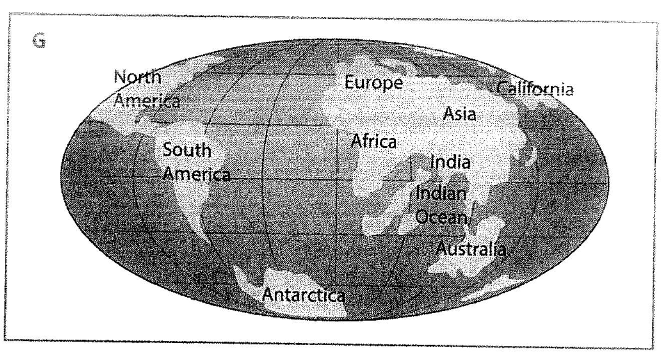
Earth around 135 millions years ago as Pangaea continues to break up.



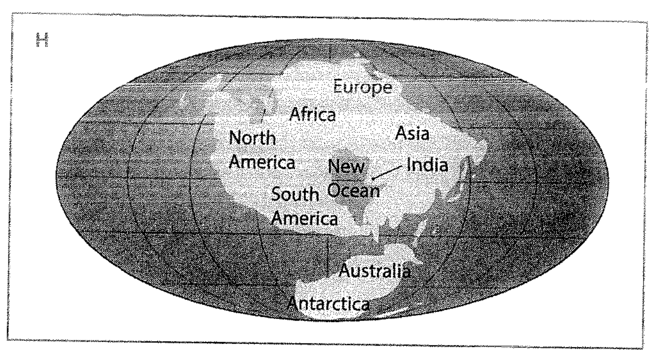
Earth around 100 million years ago with further break up of Pangaea.



Earth at present.



Earth 100 million years in future using present-day plate motions as a guide. Note bigger Atlantic Ocean and how Africa has split and collided with Europe.



Using present-day plate motions as a guide, in approximately 250 million years, Earth may be close to another supercontinent.

Figure 12-12. Changes in positions of Earth's landmasses from 700 million years ago to 250 million years into the future because of plate tectonics

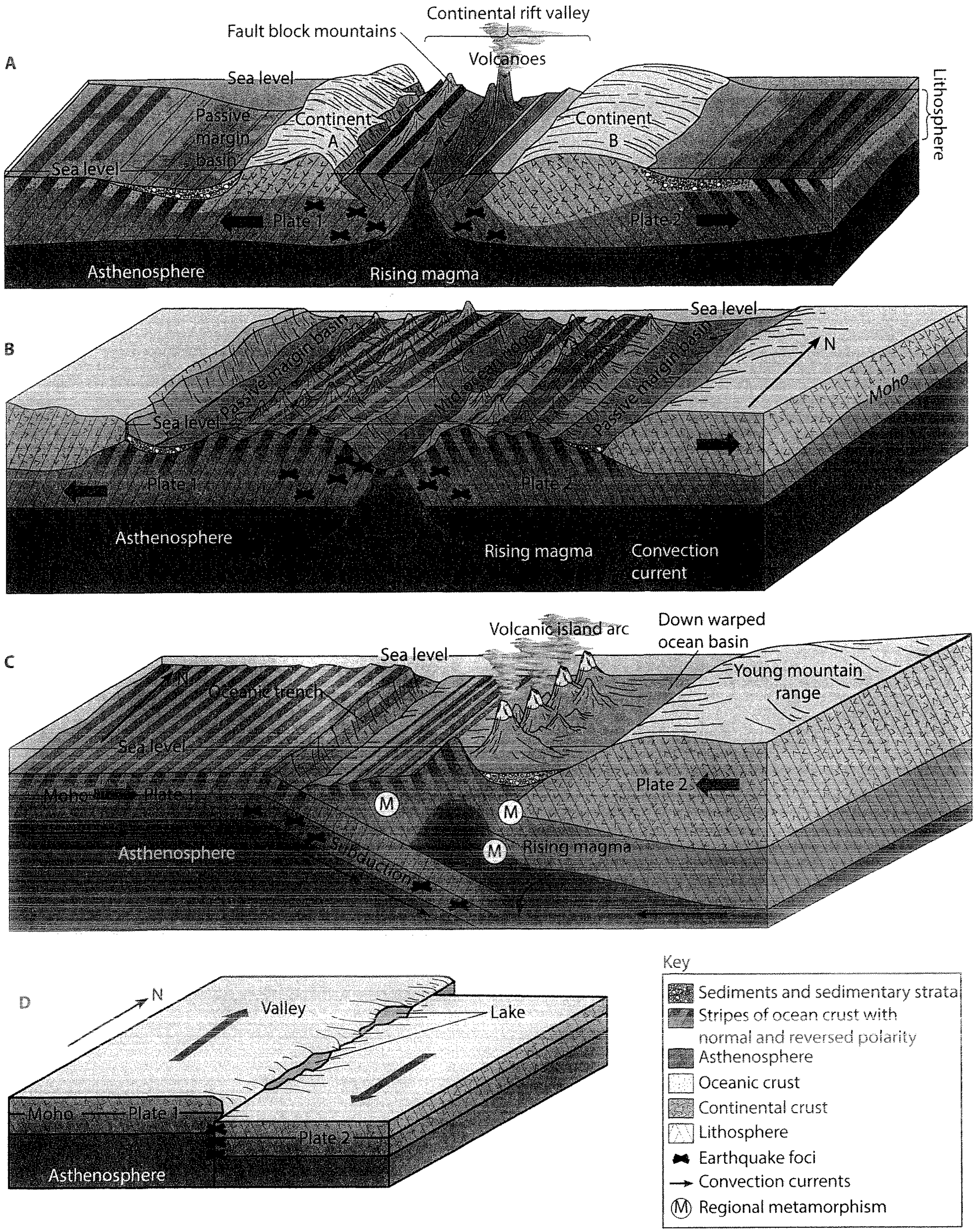


Figure 12-13. Types of plate boundaries: (A) Diverging plate boundaries in the continental crust result in a rift valley. (B) Diverging plate boundaries in the ocean result in a mid-ocean ridge, shallow-depth earthquakes, igneous intrusions, extrusions of lava flows, volcanoes, and passive margin basins in a down-warped part of crust. Plate 1 is moving west and plate 2 is moving east. (C) Converging plate boundaries result in an oceanic trench, volcanic island arcs, igneous intrusions, regional metamorphism, young mountains, and subduction of oceanic plate. Earthquake foci exist at various depths, indicating subductions. Plate 1 is moving east and plate 2 is moving west. (D) Transform plate boundaries result in many shallow-focus earthquakes and little to no igneous activity. Plate 1 is moving north and plate 2 is moving south.

- both plates with continental crust on top
- one plate with oceanic crust and the other with continental crust on top

Where two plates with oceanic crust or oceanic and continental crust at their edges converge, the denser of the two plates sinks under the other plate in a process called **subduction.** As illustrated in Figure 12-13C and the Tectonic Plates map in the *Earth Science Reference Tables,* these regions of subduction of one oceanic plate under another result in ocean trenches and volcanic island arcs. The bending down of the subducting plate warps the crust, producing a long, steep, and narrow depression called an **ocean trench.** Some of these trenches are deeper below sea level than the highest mountains are above sea level. The subducting plate also results in magma bodies. Some of the magma breaks through Earth's solid surface and forms a series of volcanoes and volcanic islands—an **island arc.** The subducting process also results in a large amount of earthquake activity following the slope of the subducting plate into the bottom portions of the lithosphere. Very deep earthquakes only occur within subducting zones. The heat and pressure of the subduction causes large areas of crustal rocks to become metamorphosed in a process called "regional metamorphism."

If there is a continent near the two converging plates with oceanic crust, the crust at the margin of the continent may become bent down producing a down-warped ocean basin that is the site of much deposition of sediments. (See Figure 12-13C.) The sediments come from the eroding island arcs and the edge of the continents. Many of the rocks of eastern New York State formed in this type of down-warped basin before the formation of the supercontinent Pangaea.

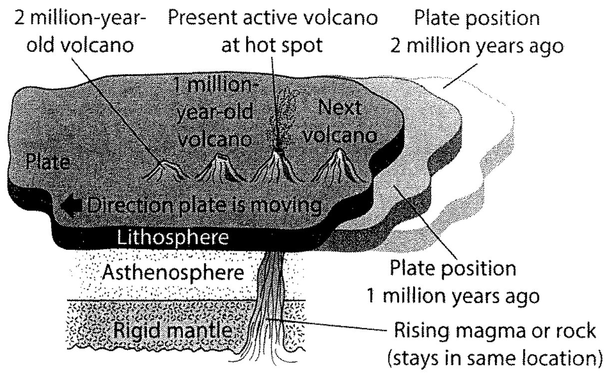
Where a plate with oceanic crust on top converges with a plate with continental crust on top, the denser oceanic crust subducts under the continental lithosphere. An ocean trench off the coast of a continent often forms from this event. The magma that forms from the subduction doesn't create an island arc because the continent is above the region of magma formation. What forms instead are relatively new mountain ranges called **young mountains.** Like the Cascades in western Oregon and Washington, these mountain ranges may be mostly volcanic. They may also be a combination of volcanic, faulted, and folded.

When two plates with continents at their edges converge, the two plate edges bunch up together, causing a great thickening of the crust and lithosphere. This bunching up creates the highest of young mountains—such as the Himalayas, where India is colliding with Asia.

Plate convergence that results in the growth of young mountain ranges is called orogeny. The term is also used to indicate the time when mountain building occurs. Refer to Important Geologic Events in New York within Geologic History of New York State in the *Earth Science Reference Tables,* and you will note the four orogenies (Grenville, Taconian, Acadian, and Alleghenian) that have resulted in mountains in New York State and surrounding regions.

Transform Plate Boundaries When two plates collide by sliding past each other, the boundary is called a **transform plate boundary.** The dragging of lithospheric rocks along the edges of the transform boundaries builds up much potential energy in rocks; this energy is eventually released as kinetic

A



B

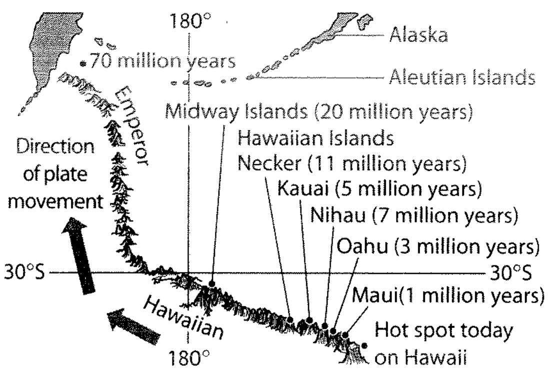


Figure 12-14. Hot spots, rising magma, and plate movements: It is believed that rising magma from the mantle melts through the plates of the lithosphere, forming volcanoes at hot spots. As the plate moves, new hot spots and volcanoes form, as shown in diagram A. The Hawaiian Islands' Emperor Seamount (underwater volcanoes) Trail was created by movements of the Pacific plate over an area of rising magma, as shown in diagram B. Note how the Pacific plate may have changed direction some 25 million to 30 million years ago or the rising hot material changed its location.

mechanical energy in the form of earthquakes. The San Andreas fault system in California is an example of a transform plate boundary between the North American and Pacific plates.

Driving Forces of Plate Tectonics

While most scientists accept the major part of the plate tectonic theory, there is still much debate about what makes the plates move. The most accepted theory is that mantle convection currents drag or push the plates apart at places where plates diverge. The exact location of these convection currents is hotly debated. The energy source for these convection currents is the heat of Earth's interior, which causes hotter, less dense parts of the mantle to rise under diverging plates. Gravity pulls down the cooler, more dense regions of the mantle, causing falling convection currents in subduction areas. (See Figures 12-11, 12-13, and 12-15 for illustrations of convection in the mantle.)

Hot Spots

One major aspect of lithosphere and crust that is difficult to explain by the conventional plate tectonic theory concerns major regions of volcanic activity in the interior parts of plates away from plate boundaries. These regions are called **hot spots.** Examples include the big island of Hawaii, the region around Yellowstone National Park in Wyoming and Montana, and maybe even the Adirondack Mountains of New York State. See the hot spots on Tectonic Plates in the *Earth Science Reference Tables.*

Scientists have proposed that hot spots occur where rising material from the lower mantle remains stationary for millions of years. When a plate moves over the rising materials, it melts its way to or near the surface to form a hot spot. Hot spots become regions of intrusive and extrusive volcanic activity that can build volcanoes and lava flows and push up regions of the crust to form mountains. Because the plate keeps moving over the rising materials, a series of volcanic mountains form for thousands of miles. These trails of hot-spot features can be used to infer past movements of the plates that moved over the hot spots. See Figure 12-14 to help you understand rising materials and hot spots.

Effects of Plate Tectonics

The movements of the plates for 3 to 4 billion years in the past and for untold millions of years in the future has had and will continue to have many effects on Earth and its inhabitants. Many of these effects are described in the sections that follow.

Appearance of Continents The outlines of the present-day continents appear to fit together like the pieces of a jigsaw puzzle because supercontinent Pangaea split apart starting approximately 225 million years ago, and a few pieces have rejoined one another. This can be seen in Figure 12-12 and in the Inferred Positions of Earth's Landmasses section of the Geologic History of New York in the *Earth Science Reference Tables.* Ⓡ

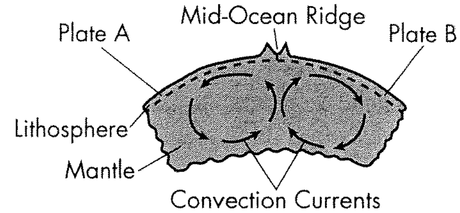


Figure 12-15. Model of convection currents in Earth's mantle

Features of Landmasses Similarities in minerals, rocks, fossils, age, and structure features of mountain ranges are found at places where the continents and other landmasses may have fitted together in the past. These similar features on different landmasses indicate a commonality in age and origin. Today the continents are separated, and their respective life forms are often greatly different. The variation in life forms on the different land areas is a result of evolution. However, fossil evidence shows that in the past many plants and animals, such as the Glossopteris fossils of Figure 12-16, were the same throughout the world. Such a wide distribution of the same plants and animals probably could not have occurred unless the continents were connected. Figure 12-16 shows some of the now separated locations that have rocks, minerals, fossils, and mountain structures in common. These similarities suggest that the land areas were together when these features were formed, and that these areas have since separated as the plates moved.

As the plates move portions of Earth's surface to new locations, rocks are exposed to different climate conditions. The finding of rocks near the

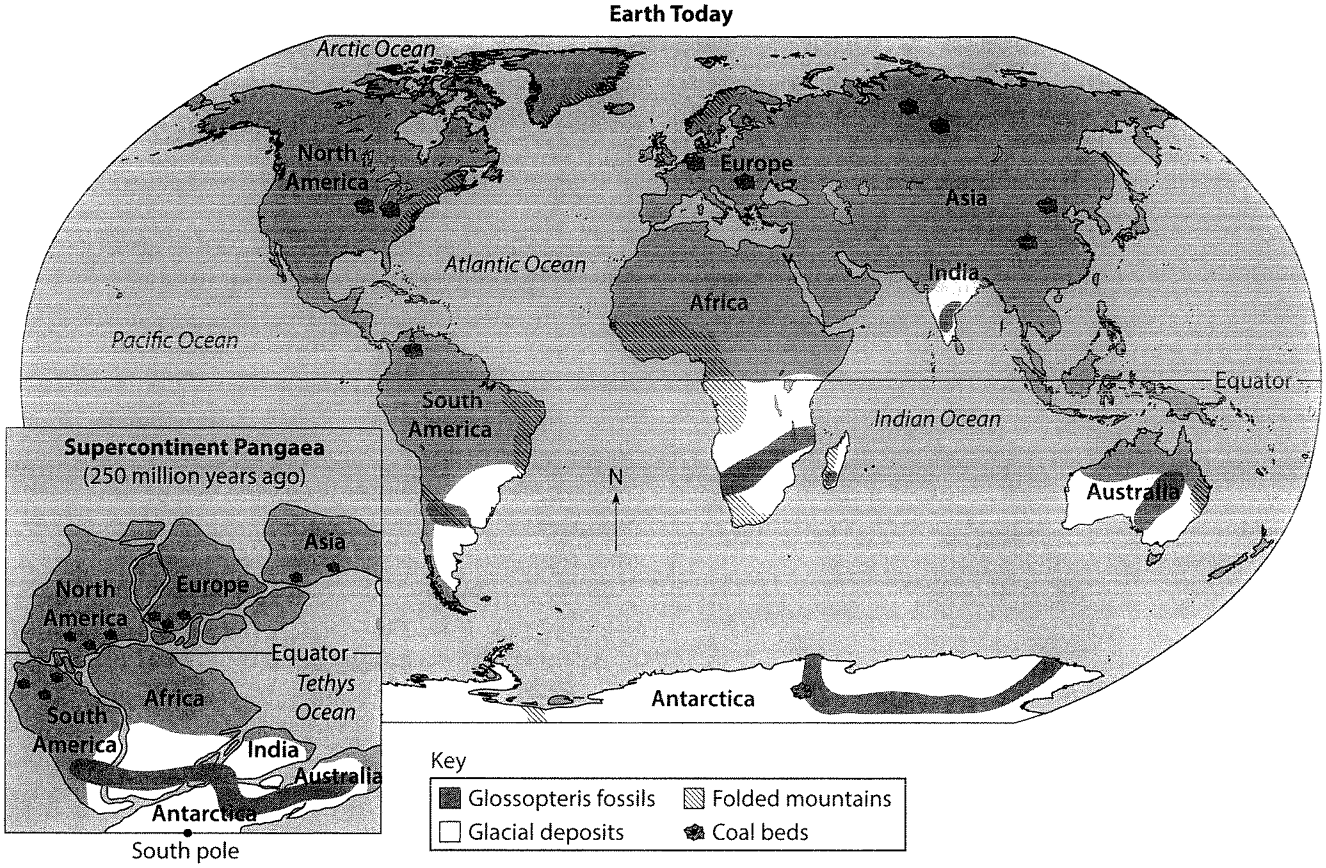


Figure 12-16. Changing features of landmasses due to plate movements: Many features of Earth's landmasses in rocks more than 250 million years old don't make sense unless the landmasses were in different locations approximately 250 million years ago when the supercontinent Pangaea existed.

equator with evidence of glacial erosion and deposition and rocks near the poles with coal deposits of the same ages indicates a climate pattern of hot near the poles and cold near the equator. The probable answer to this dilemma is that plate movements have changed the locations of the landmasses.

Age and Heat Patterns of Oceanic Rocks As the magma rises and forms basaltic igneous rocks at the mid-ocean ridges, it spreads outwards away from the ridges with divergence. This divergence of the plates is illustrated by dating samples of the oceanic basaltic rocks. The farther the sample is from the center of a mid-ocean ridge, the older the igneous rock is. The rocks are dated using the methods of radioactive-decay dating.

Another similar pattern is indicated from heat flow measurements taken from the basaltic ocean crust. Measurements indicate that heat decreases as distances from the mid-ocean ridges increase. This makes sense because the hottest rocks should be closest to the magma and lava from which they formed.

Magnetic Patterns of Oceanic Basaltic Rocks The divergence of the oceanic lithosphere and crust at mid-ocean ridges is shown by patterns in magnetism of the oceanic-basaltic rocks. Earth's magnetic poles flip-flop in polarity (north changes to south and south changes to north) in periods of thousands of years in a process called reversal of Earth's magnetic polarity. The reasons for these magnetic reversals and the question of whether the magnetic reversals are cyclic or non-cyclic have not been answered. What is known is that Earth's magnetic field has reversed hundreds of times since the magnetic field's origin, probably billions of years ago. (See Figure 12-17.)

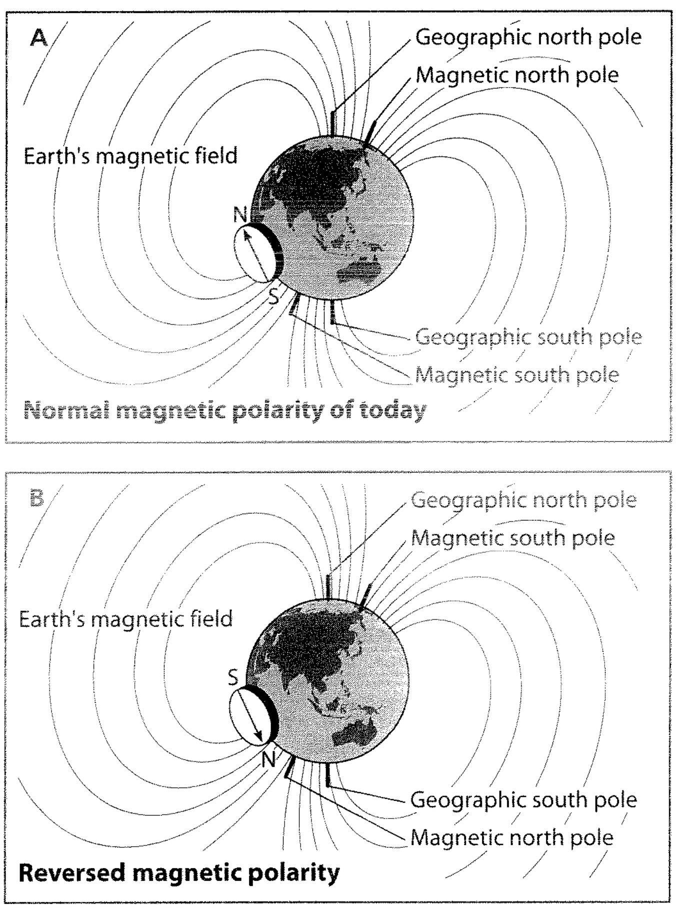


Figure 12-17. Normal and reversed polarity of Earth's magnetism: Earth's magnetic field flip-flops from normal polarity to reversed polarity in time spans of thousands of years.

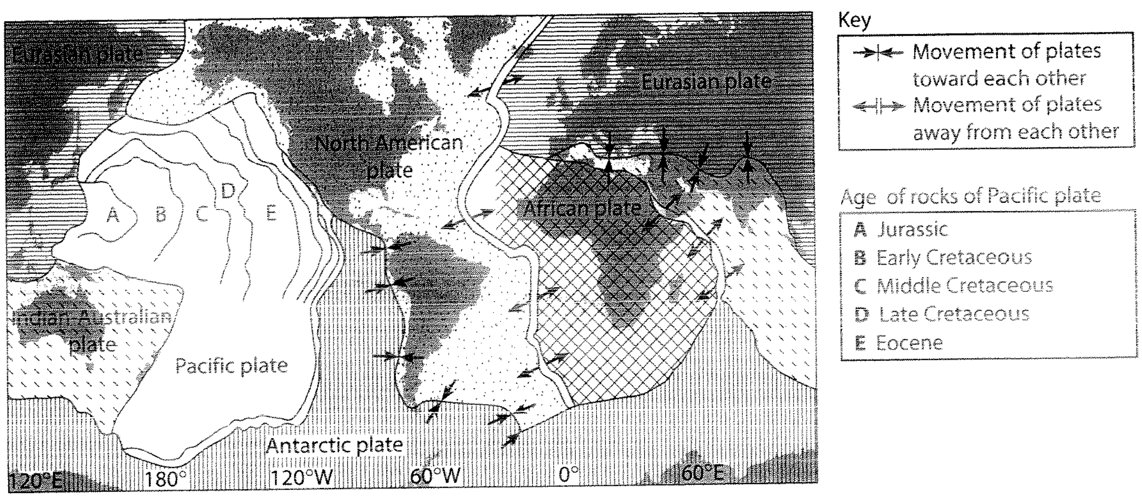
When basaltic rock crystallizes at the mid-ocean ridges, its magnetic minerals are aligned; therefore, they record the particular polarity when the magma and lava solidify. Normal polarity is when magnetic north is near the north geographic pole and magnetic south is near the south geographic pole—as is true today. Reversed polarity is when magnetic north is near the south geographic pole and magnetic south is near the north geographic pole. It has been found that there is a pattern of corresponding stripes of basaltic rock on either side of the mid-ocean ridges of normal and reversed polarity. This evidence suggests that the corresponding stripes were formed at similar times, and the sea-floor spreading has separated them during divergence. These stripes are illustrated on Figure 12-13 . Note that these stripes are not a visual feature but a pattern only indicated by magnetic instruments used in airplanes or oceanographic research ships.

of Plate Tectonics The movement of the plates has had and ...nue to have other effects on Earth and its inhabitants:

- ...ironmental hazards, such as volcanic eruptions, earthquakes, and ...unamis
- changes in Earth's climate and weather, such as altering the locations of land and ocean areas and creating mountains to change wind patterns
- changes in the factors that cause our day-to-day weather by changing the distribution of land and ocean areas and other features, such as mountains and large continental regions
- the rock cycle
- the major landscape features of Earth—continents, ocean basins, mountains, plains, and plateaus
- exposing rocks to weathering and erosion that carve the details of the solid Earth surface and form sediments

Review Questions

Base your answers to questions 42 through 48 on the following diagram. The diagram is an earlier tectonic-plate model that represents one possible interpretation of the movements of Earth's rock surfaces according to the theory of plate tectonics. According to this interpretation, Earth's lithosphere consists of several large plates that are moving in relationship to one another. The arrows in the diagram show some of this relative motion of the plates. The diagram also shows the age of formation of the igneous rocks that make up the oceanic crust of the northern section of the Pacific plate.



42. According to the *Earth Science Reference Tables*, during which geologic time period were the continents of North America, South America, and Africa closest together?

(1) Tertiary
(2) Cretaceous
(3) Triassic
(4) Ordovician

43. According to the theory of plate tectonics, the distance between two continents on opposite sides of a mid-oceanic ridge will generally

(1) decrease
(2) increase
(3) remain the same

44. Which statement is best supported by the relative movement shown by the arrows in the diagram?

(1) North America and South America are moving toward each other.
(2) The Indian-Australian plate is moving away from the Eurasian plate.
(3) The African plate and Eurasian plate are moving away from the North American plate.
(4) The Antarctic plate is moving away from the North American plate.

45. The boundaries between all of these plates are best described as the sites of

(1) frequent crustal activity
(2) deep ocean depths
(3) continental boundaries
(4) magnetic age pattern

46. Which geologic structure is represented by the double line separating the North American plate from the African and Eurasian plates?

(1) thick continental crust
(2) thick layers of sediment
(3) mid-ocean ridge
(4) granitic igneous rock

47. Which provides the best explanation of the mechanism that causes these plates to move across Earth's surface?

(1) convection currents in the mantle
(2) faulting of the lithosphere
(3) the spin of Earth on its axis
(4) prevailing wind belts of the troposphere

48. The age of formation of the igneous rocks A, B, C, D, and E that make up the oceanic crust of the northern half of the Pacific plate suggests that this section of the Pacific plate is generally moving in which direction?

(1) from north to south (3) from west to east
(2) from south to north (4) from east to west

---

49. Scientists theorize that Africa and South America were once part of the same large continent. Cite two pieces of evidence that support this theory.

50. Which statement best supports the concept that continents have shifted position?

(1) Basaltic rock is found to be progressively younger at increasing distances from a mid-ocean ridge.
(2) Marine fossils are often found in deep-well drill cores.
(3) The present continents appear to fit together as pieces of a larger landmass.
(4) Areas of shallow-water seas tend to accumulate sediment, which gradually sinks

51. Describe two expected similarities between rock samples found equal distances from and on opposite sides of the Mid-Atlantic Ridge.

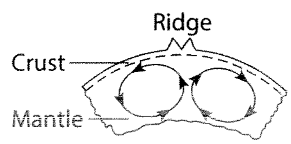
52. Which feature is commonly formed at a plate boundary where oceanic crust converges with continental crust?

(1) a mid-ocean ridge (3) a transform fault
(2) an oceanic trench (4) new oceanic crust

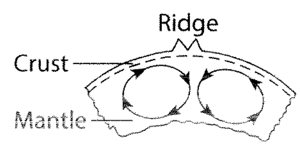
53. Evidence of subduction exists at the between the

(1) African and South American plates
(2) Indian-Australian and Antarctic plates
(3) Pacific and Antarctic plates
(4) Nazca and South American plates

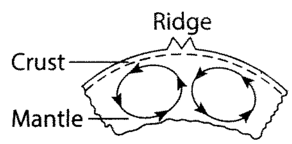
54. Which of the following cross-sectional diagrams best represents a model for the movement of rock material below the crust along the mid-Atlantic ridge?



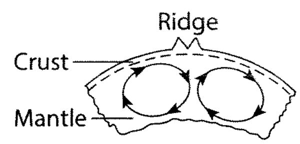
(1)



(3)

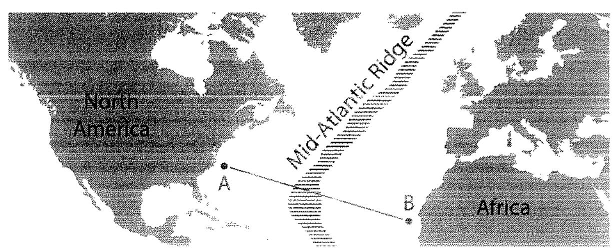


(2)

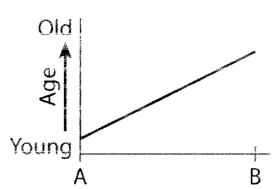


(4)

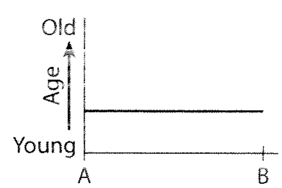
55. The following drawing represents the ocean floor between North America and Africa.



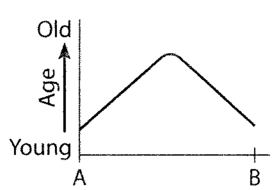
Which graph best represents the age of the bedrock in the ocean floor along line AB?



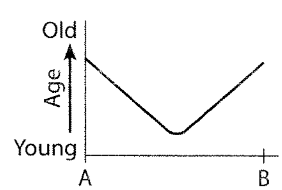
(1)



(3)



(2)

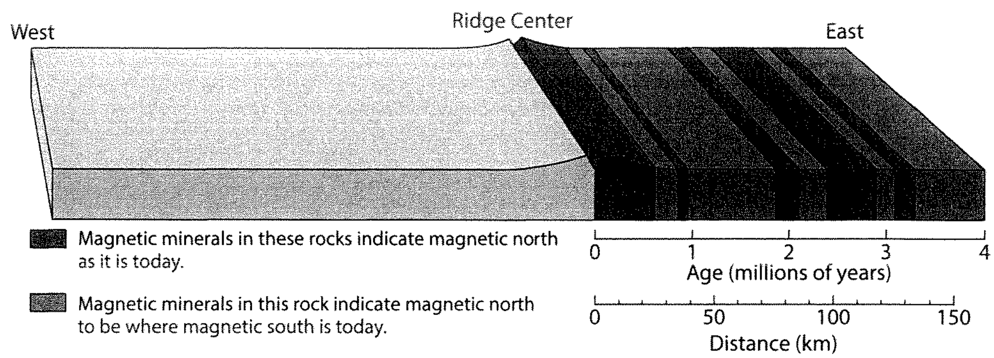


(4)

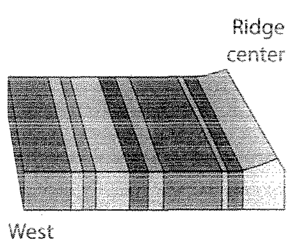
56. Igneous materials found along mid-ocean ridges contain magnetic particles that show reversal of magnetic orientation. This is evidence that

(1) volcanic activity has occurred constantly throughout history
(2) Earth's magnetic poles have exchanged their positions
(3) igneous materials are always formed beneath oceans
(4) Earth's crust does not move

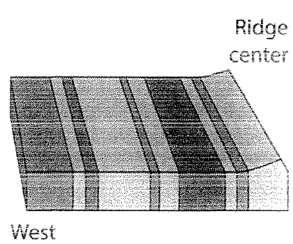
Base your answers to questions 57 through 61 on the following diagram. The diagram shows the magnetic orientation of igneous rock on the sea floor on the east side of a mid-ocean ridge. The pattern on the west (left) side of the ridge has been omitted. The age of the igneous rock and its distance from the ridge center are shown.



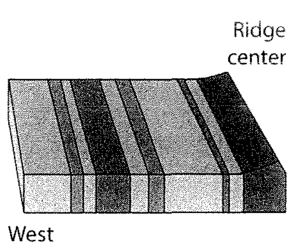
57. Which of the following diagrams best represents the pattern of magnetic orientation in the sea floor on the west (left) side of the ocean ridge?



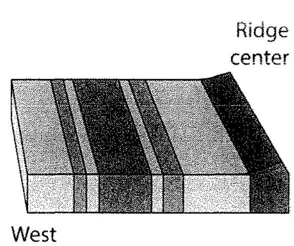
(1)



(3)



(2)



(4)

58. According to the diagram, what is the approximate rate of sea-floor spreading?

(1) 1 km/million years
(2) 2 km/million years
(3) 40 km/million years
(4) 50 km/million years

59. Which inference can best be made from the diagram?

(1) The orientation of Earth's magnetic field has reversed with time.
(2) The size of the continents has changed with time.
(3) The elevation of sea level has changed with time.
(4) The amount of fossil material preserved in the igneous rock has changed with time.

60. The crustal material on both sides of the ridge indicates that the tectonic plates are

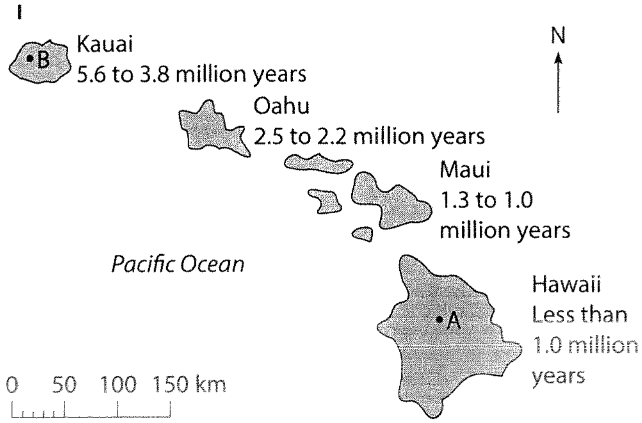
(1) diverging
(2) converging
(3) not moving
(4) moving parallel to the ridge

61. As the distance from the center of the ridge increases, the age of the rocks

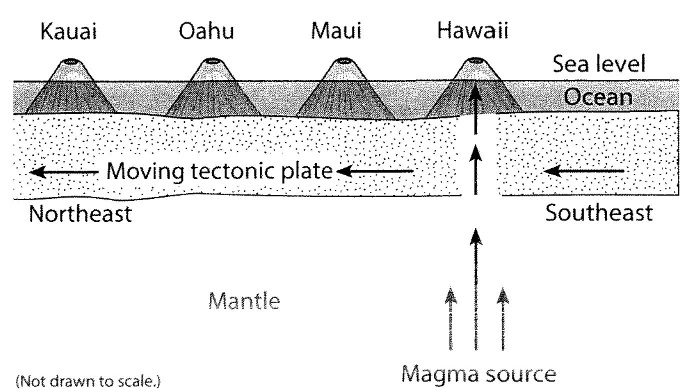
(1) decreases
(2) increases
(3) remains the same
(4) increases and decreases in a cyclic pattern

Base your answers to questions 62 through 66 on the following diagrams. Diagram I is a map showing the location and bedrock age of some of the Hawaiian Islands. Diagram II is a cross section of an area of Earth that illustrates a stationary magma source (rising magma and hot spot) and the process that could have formed the islands.

I



II



62. If each island formed as the tectonic plate moved over the magma source in the mantle, as shown in diagram II, where would the next volcanic island form?

(1) northwest of Kauai
(2) northeast of Hawaii
(3) southeast of Hawaii
(4) between Hawaii and Maui

63. Compared to the continental crust of North America, the oceanic crust in the area of the Hawaiian Islands is probably

(1) thinner and similar in composition
(2) thinner and different in composition
(3) thicker and similar in composition
(4) thicker and different in composition

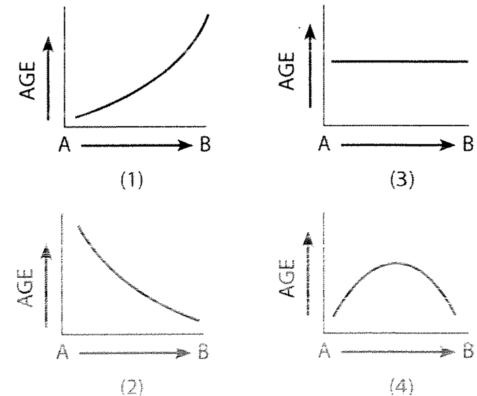
64. Volcanic activity like that which produced the Hawaiian Islands is usually closely correlated with

(1) nearness to the center of a large ocean
(2) sudden changes in Earth's magnetic field
(3) frequent major changes in climate
(4) frequent earthquake activity

65. Which of the Hawaiian Islands has the greatest probability of a volcanic eruption?

(1) Kauai
(2) Oahu
(3) Maui
(4) Hawaii

66. Which of the following graphs best represents the ages of the Hawaiian Islands, comparing them from point A to point B?



67. What do mid-ocean ridges and hot spots have in common?

(1) They are associated with rising magma.
(2) They are always associated with present-day plate boundaries.
(3) They commonly are associated with earthquakes of great depth.
(4) Neither is associated with plate motions.

68. Which observation provides the strongest evidence for the inference that convection cells exist within Earth's mantle?

(1) Sea level has varied in the past.
(2) Marine fossils are found at elevations high above sea level.
(3) Displaced rock strata are usually accompanied by earthquakes and volcanoes.
(4) Heat-flow readings vary at different locations in Earth's crust.

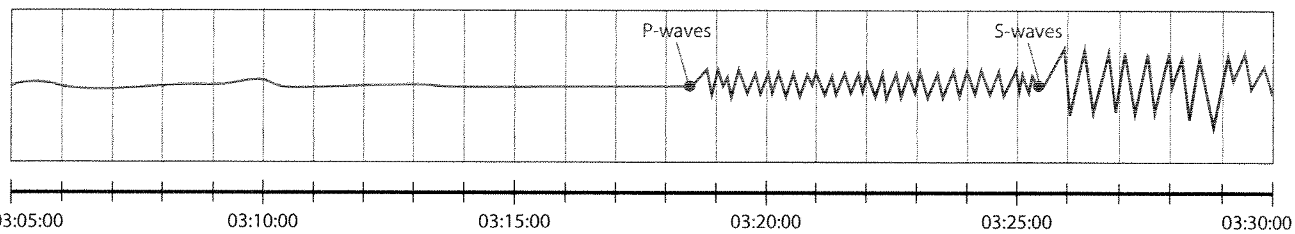
Practice Questions

Directions

Review the Test-Taking Strategies section of this book. Then answer the following questions. Read each question carefully and answer with a correct choice or response.

Part A

1 The following is a record of earthquake waves from a seismic station.



Which information can be determined by using this record?

(1) the depth of the earthquake's focus
(2) the direction of the earthquake's focus
(3) the location of the earthquake's epicenter
(4) the distance to the earthquake's epicenter

2 Decide which statement best describes the relationship between the travel rates and travel times of earthquake P-waves and S-waves from the focus of an earthquake to a seismic station.

(1) P-waves travel at a slower rate and take less time.
(2) P-waves travel at a faster rate and take less time.
(3) S-waves travel at a slower rate and take less time.
(4) S-waves travel at a faster rate and take less time.

3 Where is the thickest part of Earth's crust?

(1) at the edges of the continental shelves
(2) at mid-ocean ridges
(3) under continental mountain ranges
(4) under volcanic islands

4 What is the material between 2900 kilometers and 5200 kilometers below Earth's surface inferred to be?

(1) an iron-rich solid
(2) an iron-rich liquid
(3) a silicate-rich solid
(4) a silicate-rich liquid

5 An earthquake's P-waves traveled 4800 kilometers and arrived at a seismic station at 5:10 P.M. At approximately what time did the earthquake occur?

6 The theory of plate tectonics suggests that the

(1) continents moved due to changes in Earth's orbital speed
(2) continents moved due to the Coriolis effect caused by Earth's rotation
(3) present-day continents of South America and Africa are moving toward each other
(4) present-day continents of South America and Africa once fit together like puzzle pieces

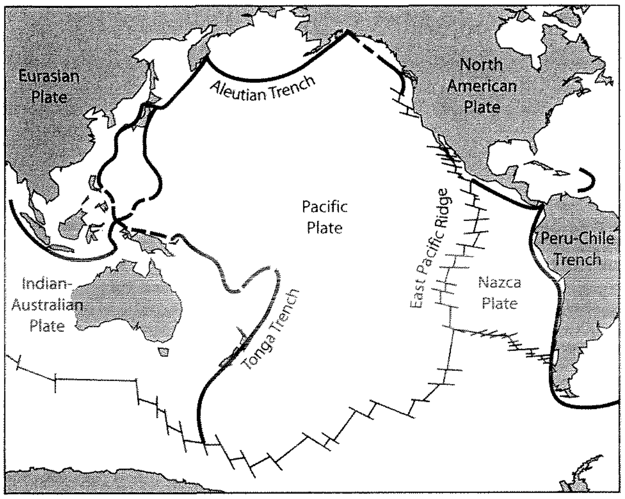
7 What is one of the main reasons volcanic eruptions can be predicted in enough time to allow people to escape?

(1) Many volcanoes emit X-rays before eruptions.
(2) Most volcanoes form a new crater before major eruptions.
(3) Most volcanoes swell in volume before major eruptions.
(4) Most animals escape from an area before most eruptions.

8 What is the best evidence that earthquakes and crustal movements are associated?

(1) associations of earthquake belts and young mountain ranges
(2) association of earthquake belts and belts of old metamorphic rocks
(3) studying faults in lava flows
(4) samples of rocks and fluids from deep drill holes

Base your answers to questions 9 through 11 on the following map. The map shows a mid-ocean ridge and trenches in the Pacific Ocean.



9 Movement of the plates shown in the diagram is most likely caused by
(1) the revolution of Earth
(2) the erosion of Earth's crust
(3) shifting of Earth's magnetic poles
(4) convection in Earth's mantle

10 The crust at the mid-ocean ridge is composed mainly of
(1) granite (3) shale
(2) basalt (4) limestone

11 Mid-ocean ridges such as the East Pacific Ridge are best described as
(1) mountains containing folded sedimentary rocks
(2) plateaus containing fossils of present-day marine life
(3) sections of the ocean floor that contain the youngest oceanic crust
(4) sections of the ocean floor that are the remains of a submerged continent

---

12 At which depth below Earth's surface is the density most likely 10.5 grams per cubic centimeter?
(1) 1500 km (3) 3500 km
(2) 2000 km (4) 6000 km

13 What happens to P-waves and S-waves from a crustal earthquake when the waves reach Earth's core?
(1) S-waves are transmitted through the outer core, but P-waves are not transmitted.
(2) P-waves are transmitted through the outer core, but S-waves are not transmitted.
(3) Both P-waves and S-waves are transmitted through the outer core.
(4) Neither P-waves nor S-waves are transmitted through the outer core.

14 At a depth of 2000 kilometers, the temperature of the stiffer mantle is inferred to be
(1) 6500°C (3) 3500°C
(2) 4200°C (4) 1500°C

15 Tsunamis can be directly caused by
(1) offshore surface ocean currents
(2) gravitational effects of the moon
(3) underwater earthquakes
(4) underwater lava flows at mid-ocean ridges

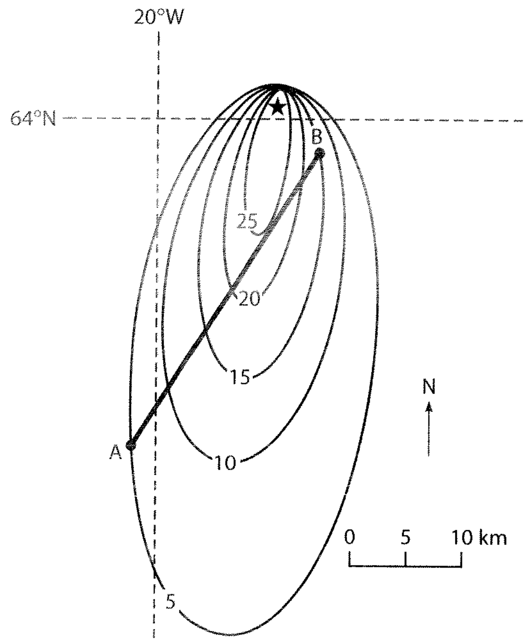
16 A large earthquake occurred at 45° N, 75° W on September 5, 1994. Which location in New York State was closest to the epicenter of the earthquake?
(1) Buffalo
(2) Massena
(3) Albany
(4) New York City

17 Oxygen is the most abundant element by volume in Earth's
(1) inner core
(2) crust
(3) hydrosphere
(4) troposphere

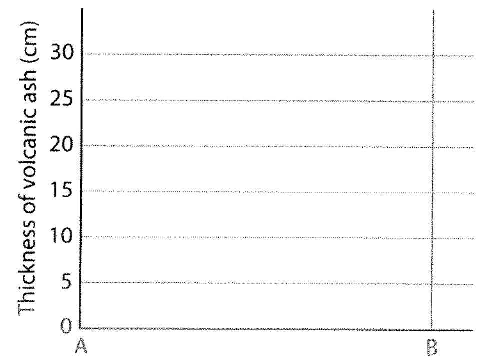
18 Which geologic event occurred most recently?
(1) initial opening of the Atlantic Ocean
(2) metamorphism of the rocks of the Hudson Highlands
(3) formation of the Catskill delta
(4) collision of North America and Africa

Part B

Base your answers to questions 19 through 21 on the following map. The star symbol represents a volcano located on the mid-Atlantic ridge in Iceland. The isolines represent the thickness, in centimeters, of volcanic ash deposited from an eruption of this volcano. Points A and B represent locations in the area.



19 On the grid below and using the directions below, construct a profile of the ash thickness between point A and point B.



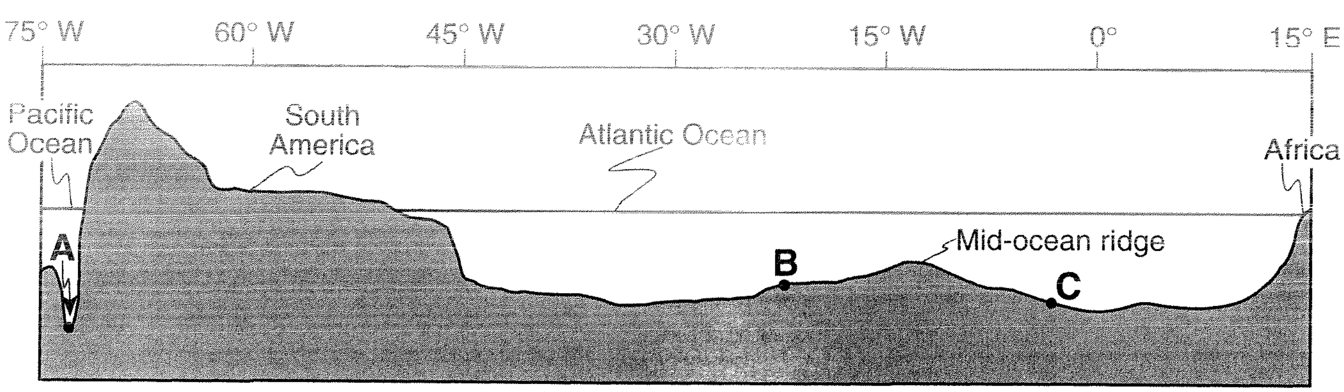
a. Plot the thickness of the volcanic ash along line AB by marking with a dot each point where an isoline is crossed by line AB. [2]

b. Connect the dots to complete the profile of the thickness of the volcanic ash. [1]

20 State one factor that could have produced this pattern of deposition of the ash. [1]

21 State why volcanic eruptions are likely to occur in Iceland. [1]

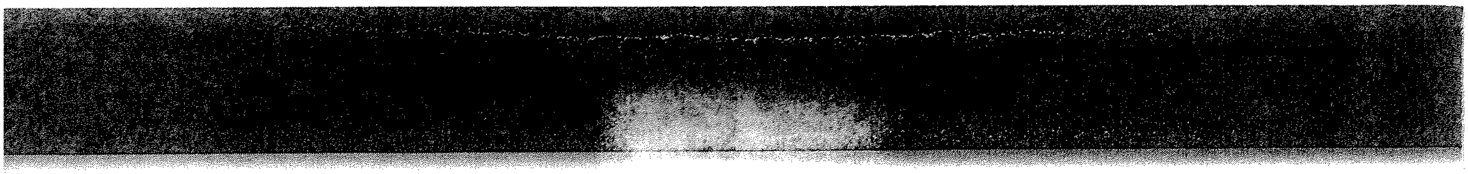
Base your answers to questions 22 through 24 on the cross section below, which shows the major surface features of Earth along 25° *S* latitude between 75° *W* and 15° E longitude. Points *A*, *B*, and *C* represent locations on Earth's crust.



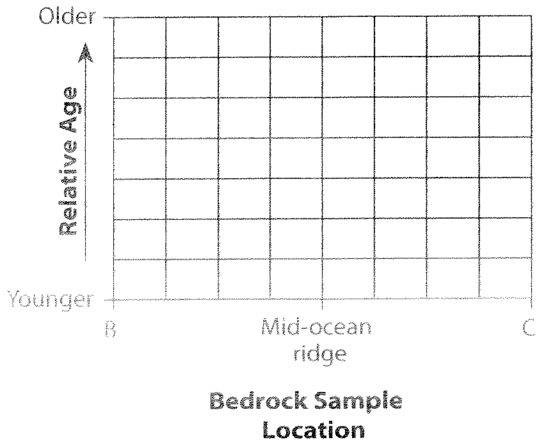
(Not drawn to scale)

22 Identify the crustal feature located at point *A*. [1]

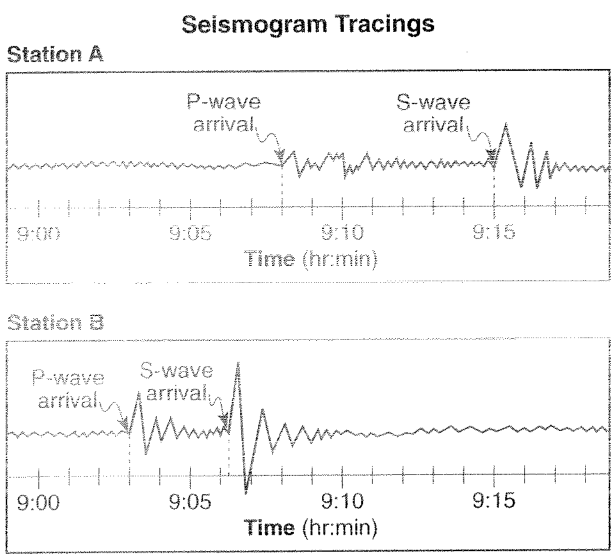
23 Identify the tectonic plate motion that is causing an increase in the distance between South America and Africa. [1]



24 Bedrock samples were taken at the mid-ocean ridge and points *B* and *C*. On the following grid, draw a line to show the relative age of the bedrock samples between these locations. [1]



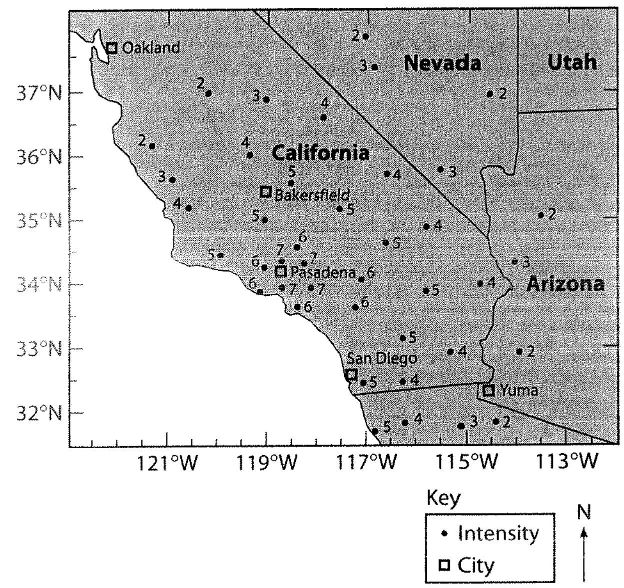
Base your answers to questions 25 and 26 on the diagram below, which shows two seismogram tracings, at stations *A* and *B*, for the same earthquake. The arrival times of the *P*-waves and *S*-waves are indicated on each tracing.



25 Explain how the seismic tracings recorded at station *A* and station *B* indicate that station *A* is farther from the earthquake epicenter than station *B*. [1]

26 Seismic station *A* is located 5,400 kilometers from the epicenter of the earthquake. How much time would it take for the first *S*-wave produced by this earthquake to reach seismic station *A*? [1]

Base your answers to questions 27 through 30 on the map below.



An earthquake occurred in the southwestern United States. Intensity units were plotted for several locations on a map. (As the numerical value of intensities increases, the damaging effects of the earthquake waves also increases.)

27 Using an interval of 2 units and starting with an isoline representing 2 units, draw an accurate isoline map of earthquake intensity. [4]

28 State the name of the city that is closest to the earthquake epicenter. [1]

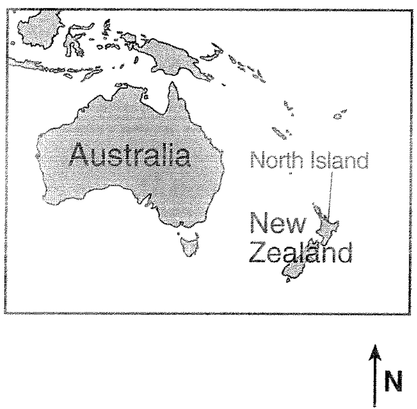
29 Identify the most likely cause of earthquakes that occur in the area shown on the map. [1]

30 A newspaper article indicates that a major earthquake is expected in the local area. State three actions individuals could take to increase safety or reduce injury from an earthquake. [3]

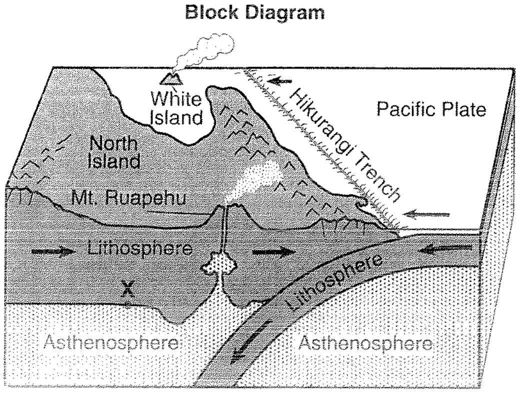
Part C

Base your answers to questions 31 through 34 on the map and block diagram below. The block diagram shows a portion of North Island in New Zealand. The Hikurangi Trench is shown forming at the edge of the Pacific Plate. Point *X* is at the boundary between the lithosphere and the asthenosphere.

Map



Block Diagram



(Not drawn to scale)

31 State the approximate temperature at point *X*. [1]

32 On what tectonic plate are both North Island and White Island located? [1]

33 Describe the type of tectonic plate motion that formed the Hikurangi Trench. [1]

34 Describe *one* action that people on North Island should take if a tsunami warning is issued. [1]

Use the following information and your knowledge of earth science to answer questions 35 through 39.

Studies of the planet Mars from 1965 to the present have allowed scientists to infer that like Earth, Mars has or had hot spots; but unlike Earth there is no evidence of plates or movement of plates.

35 Describe a landscape feature composed of igneous rocks that you would expect to find on Mars and explain why you would expect to find it there. [2]

36 Identify four large (hundreds of miles in length) types of landscape features that, although common on Earth, would not be expected to be found on Mars. Explain why these features would not likely be found on Mars. [4]

37 Describe two events that are common on Earth that, due to a lack of plate movements, you would not expect to occur on Mars. [2]

38 Explain why folded mountains have not been found, nor are expected to be found, on Mars. [1]

39 Discuss the likelihood of finding metamorphic rocks on Mars, and defend your conclusion. [2]

---

40 Name one region of the United States that is likely to experience a major damaging earthquake. Explain why an earthquake is likely to occur in that region. [1]

Base your answers to questions 41 through 44 on the information below and on your knowledge of Earth science.

In the 1930s, most scientists believed that Earth's crust and interior were solid and motionless. A small group of scientists were talking about "continental drift," which is the idea that Earth's crust is not stationary, but is constantly shifting and moving.

From seismic data, geophysical evidence, and laboratory experiments, scientists now generally agree that lithospheric plates move at the surface. Both Earth's surface and interior are in motion. Solid rock in the mantle can be softened and shaped when subjected to the heat and pressure within Earth's interior over millions of years.

Subduction processes are believed by many scientists to be the driving force of plate tectonics. At present, this theory cannot be directly observed and confirmed. The lithospheric plates have moved in the past and are still moving today. The details of why and how they move will continue to challenge scientists.

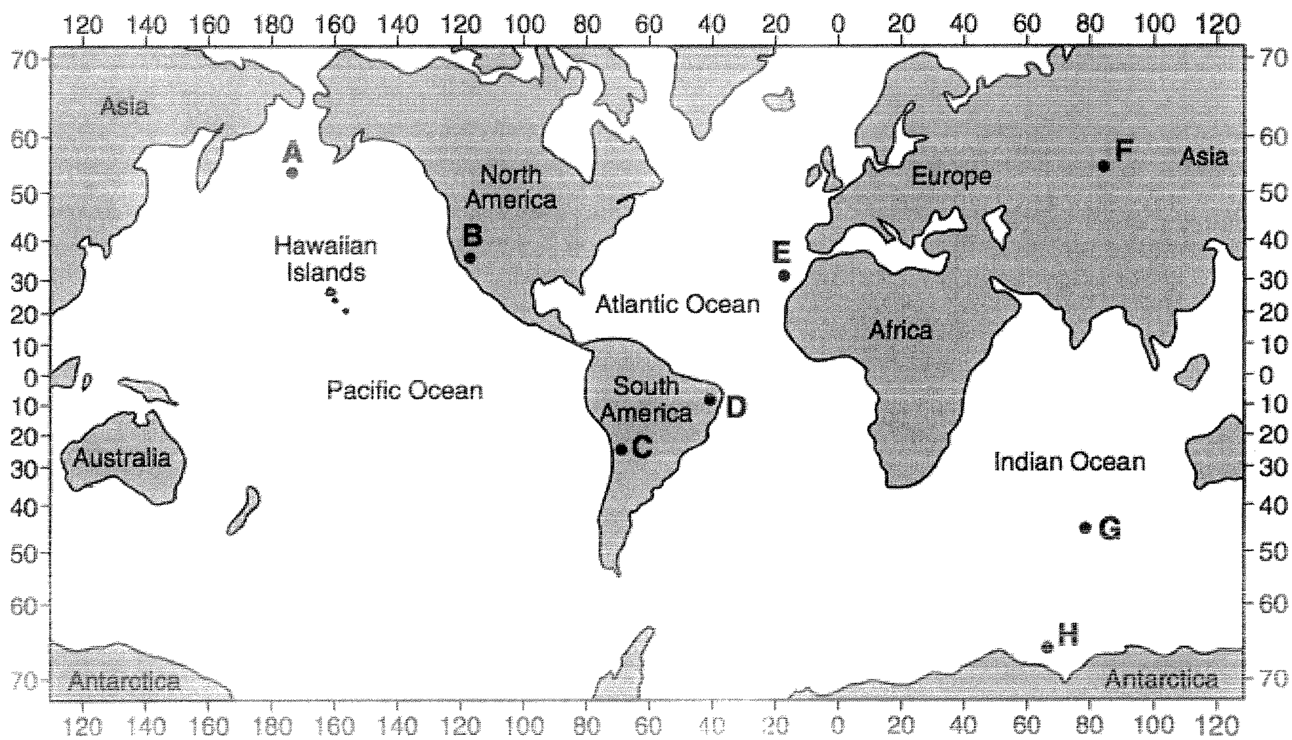
41 Earth's crust is described as "constantly shifting and moving." Give one example of geologic evidence that supports the conclusion that continents have drifted apart. [1]

42 The information given suggests that "subduction processes are the driving force of plate tectonics." Identify a specific location of a subduction zone on Earth. [1]

43 According to the *Earth Science Reference Tables,* at what inferred depth is *mantle* rock partially melted and slowly moving below the lithospheric plates? [1]

44 According to the geologic record, during which geologic time period did the lithospheric plates that made up Pangaea begin to break up? [1]

Base your answers to questions 45 through 48 on the world map shown below and on your knowledge of Earth science. Letters *A* through *H* represent locations on Earth's surface.



45 Explain why most earthquakes that occur in the crust beneath location *B* are shallower than most earthquakes that occur in the crust beneath location *C*. [1]

46 Explain why location *A* has a greater probability of experiencing a major earthquake than location *D*. [1]

47 Explain why a volcanic eruption is more likely to occur at location *E* than at location *F*. [1]

48 Explain why the geologic age of the oceanic bedrock increases from location *G* to location *H*. [1]