

Key Concepts

Major Concept (I) *The most important source of information concerning the interior of Earth is the passage of different kinds of earthquake or seismic waves through the interior and along the surface.*

Related or supporting concepts:

- Seismic waves are vibrations that propagate through the earth as a result of an earthquake, volcanism, or an explosion.
- There are two fundamental types of seismic waves, P-waves and S-waves (see fig. 3.1).
- P-waves are compressional, or pressure, waves. Particle motion is in the direction of propagation of the wave. Since it is possible to compress all states of matter, P-waves will propagate through solids, liquids, and gases (sound is a compressional wave that passes through the air).
- S-waves are shear waves. Particle motion is perpendicular to the direction of propagation of the wave. You cannot transmit shearing energy through liquids or solids, so S-waves will only pass through solids.
- We know that the outer core behaves like a liquid because S-waves will not pass through it.
- Whenever a wave passes from one material into another its velocity will change and its path will bend. The bending of the path is called refraction.
- Careful measurements of travel times of seismic waves from thousands of earthquakes to hundreds of recording stations all over the world have allowed scientists to model the internal structure of Earth as consisting of four basic layers, or regions (fig. 3.2).

Major Concept (II) *Despite the fact that we cannot sample the deep interior of Earth, we can infer a great deal about its characteristics through remote means of investigation.*

Related or supporting concepts:

- We know that the gross structure of the planet must be a series of concentric shells with fairly uniformly distributed mass in each shell. This view is supported by:
 - a. the fact that Earth spins on its axis with only a slight wobble,
 - b. the fairly uniform acceleration of gravity over the planet, and
 - c. the characteristics of seismic waves passing through Earth generated by earthquakes.
- With a knowledge of the dimensions of the planet and its internal composition, we can calculate pressure, temperature, and density with depth.

- The presence of a magnetic field around Earth and the observation of nickel-iron meteorites both suggest that the center of the planet must be rich in these metals.
- There are four major layers, or shells, that make up the planet:
 - a. the inner core,
 - b. the outer core,
 - c. the mantle, and
 - d. the crust.
- The inner core has the following characteristics:
 - a. it has a radius of about 1222 km,
 - b. it is rich in iron and nickel,
 - c. it behaves like a solid, and
 - d. it is nearly five times as dense as common surface rocks like granite.
- The outer core:
 - a. is about 2258 km thick,
 - b. has the same composition as the inner core, and
 - c. behaves like a liquid.
- The mantle:
 - a. is about 2866 km thick,
 - b. is the largest region, accounting for about 70 percent of the volume of Earth,
 - c. is composed of Mg-Fe silicates, and
 - d. behaves like a solid with the exception of a thin upper layer that behaves like a plastic.
- Details concerning temperature and density of these regions are given in table 3.1 in the text.
- There are two different types of crust, continental and oceanic.
- Continental crust:
 - a. averages about 40 km in thickness,
 - b. is composed primarily of an igneous rock called granite which is rich in Al, K, and silica, and
 - c. is relatively light.
- Oceanic crust:
 - a. is generally about 7 km thick,
 - b. is made of an igneous rock called basalt that is rich in Ca, Fe, and Mg, and
 - c. is heavier than continental crust.
- The boundary between the crust and the mantle is called the Moho.

Major Concept (III) *Another way to define distinct layers near the surface of Earth is by the way in which the material responds to applied forces. This method allows us to define two layers, a rigid upper one at the surface called the lithosphere and a deformable second layer called the asthenosphere below it (see fig. 3.3).*

Related or supporting concepts:

- Continents and ocean basins are made of different kinds of rock. Continents are composed of granite-like rocks rich in aluminum, potassium, and silica. Ocean basins are composed of basalt-like rocks rich in calcium, iron, and magnesium and relatively low in silica. Basalt has a higher density than granite.
- The speed of seismic waves increases abruptly at the boundary of the crust and mantle. This boundary is called the Mohorovičić discontinuity, or the Moho, for its discoverer Andrija Mohorovičić.
- The crust and upper mantle are rigidly attached along the Moho.
- The crust and upper mantle form a strong, rigid, layer called the lithosphere. It is about 100 km (62 mi) thick in oceanic regions and about 150 km (90 mi) thick in continental regions.
- The base of the lithosphere occurs where the temperature reaches about $650^{\circ}\text{C} \pm 100^{\circ}\text{C}$. At higher temperatures mantle rock begins to lose some of its strength.
- The lithosphere rests on top of a region in the mantle that behaves like a plastic; it deforms when subjected to stress. This layer is called the asthenosphere.
- The base of the asthenosphere is at a depth of about 350 km (217 mi).
- The asthenosphere is partially melted due to relatively high temperature and low pressure at these depths. At greater depth the mantle again behaves like a solid despite a steady increase in temperature because the greater pressure is able to prevent melting.
- The lithosphere is able to move rigidly on top of the asthenosphere.

Major Concept (IV) *Speculation about the possible fit of continents goes back in time several centuries. The earliest strong advocate of continental drift was Alfred Wegener.*

Related or supporting concepts:

- Francis Bacon (1561 - 1626) was an English scholar who first speculated about the remarkable resemblance of the western coasts of South America and Africa. He did not go so far as to say that they had once been joined.
- Other scientists and explorers would note the similarity in continental outlines, including George Buffon (1707 - 88) and Alexander von Humboldt (1769 - 1859).
- Continued study revealed that there were other lines of evidence showing remarkable similarities between continents. These included:
 - a. the distribution of fossils,
 - b. patterns of major geologic features such as faults and mountain ranges, and
 - c. the locations of distinctive rock formations.
- Edward Suess, an Austrian geologist, suggested that the Southern Hemisphere continents had once been joined in a single landmass called Gondwanaland. This idea was developed in a series of papers written between 1885 and 1909.

- Suess believed that the ocean basins were created when large regions of Gondwanaland sank and the seas invaded the land. Thus, he did not propose a fragmentation of Gondwanaland and subsequent drifting apart of the fragments.
- Continental drift was proposed at the beginning of the 20th century by two people independently, Alfred Wegener and Frank Taylor. Frank Taylor did not continue to pursue the idea, however, so we often attribute it to Wegener alone.
- Wegener was a meteorologist by training.
- Wegener believed that there was once a super continent called Pangaea that contained all landmass (see fig. 3.4 in your text). Pangaea later broke apart into two masses: Laurasia (North America and Eurasia) and Gondwanaland (Africa, South America, India, Australia, and Antarctica).
- With continued time, both Laurasia and Gondwanaland fragmented to form the pattern of continents we see today.
- The evidence used to support this idea included:
 - a. the geographical fit of the continental coastlines,
 - b. the way in which old mountain ranges and bodies of rock seemed to come together and fit when the continents were rotated back together, and
 - c. evidence from fossils.
- Wegener noticed that fossils older than 150 million years seemed to be very similar despite the fact that they were now located on different continents. This could easily be explained if the continents were once a single landmass, allowing the organisms to move freely from one place to another. Fossils younger than 150 million years from different continents exhibited very different forms, suggesting that they had evolved independently.
- Wegener believed that the forces responsible for the breakup of Pangaea and drifting of the continents were related to the rotation of Earth and tidal pull.
- A famous geophysicist of the time, Harold Jeffreys, demonstrated that these forces were not powerful enough to move continents. In addition, people could not accept the idea that the continents could plow through the oceanic crust.
- Continental drift was never widely accepted during Wegener's life.

Major Concept (V) *Following WWII, improved instrumentation was used to study the ocean basins in detail. This eventually led to evidence that supported seafloor spreading.*

Related or supporting concepts:

- Marine geologists first thought that the sea floor should be fairly smooth because of vast amounts of sediment eroded from the continents that would cover any irregularities.
- When the sea floor was finally extensively mapped following WWII, we discovered that there are major structural features that rival, and even surpass, any found on the continents. The sea floor has major mountain ranges, deep trenches, vast plateaus, and

enormous faults.

- Harry Hess, in the early 1960s, first proposed the existence of large convection cells in the mantle that act as conveyor belts for the overlying lithosphere.
- Where the lithosphere is cracked the hot mantle material is able to escape and pour onto the sea floor in active volcanism. This occurs along the axis of the oceanic mountain ranges, creating new sea floor as it hardens.
- To conserve the total surface area of Earth, a volume of material equal to that created along the ridges must be destroyed. This occurs along oceanic trenches where the sea floor is subducted into the mantle.
- The movement of the sea floor away from the ridges is called seafloor spreading.
- The ridges are also called spreading centers and trenches are called subduction zones (take a look at fig. 3.6 to see a schematic of how these all work together).
- The convection cells in the mantle are driven by heat. The heat is probably due to radioactive decay and the natural cooling of the planet.
- There are currently two proposed models of mantle convection. Some scientists believe that there are two sets of convection cells, one confined to the upper mantle above a depth of about 700 km (435 mi) and the other in the lower mantle. Other scientists think that convection occurs throughout the entire mantle from the base of the lithosphere to the core-mantle boundary.
- The movement of convection cells has historically been thought to be the driving mechanism of plate tectonics. There are now two other forces that are thought to play a major role. They are both related to gravity and involve a pulling force at the edge of the plate falling into the mantle and a pushing force at the edge of the plate located along the spreading center as it "slides" down the inclined plane formed by the elevated ridge.

Major Concept (VI) *Additional lines of evidence supporting the concept of a dynamic outer layer of Earth came from the study of earthquakes, heat flow, sampling of marine sediments, and measurements of rock magnetism.*

Related or supporting concepts:

- The geographical distribution of earthquakes forms two unmistakable patterns:
 - a. in plan view, earthquakes form narrow belts of activity that follow plate boundaries (see fig. 3.7), and
 - b. in the vicinity of trenches, earthquakes occur in descending bands called Benioff zones.
- Heat flows out of the surface of Earth everywhere but the amount of heat can vary from one location to another. In the ocean basins heat flow increases as you get closer to mid-ocean ridges and decreases away from them (see fig. 3.9). This is due to upward moving, hot mantle material beneath the ridges.
- In the late 1960s a special ship, the *Glomar Challenger*, was designed to drill into the sea floor and recover sediments and rock. A sonar positioning system allows the ship

to remain stable above the hole during drilling (see fig. 3.10). Drilling revealed that:

- a. there is no oceanic crust older than about 180 million years,
- b. the thickness of sediment increases away from the ridges,
- c. the age of surface sediment is recent everywhere, and
- d. the age of the sediment at the bottom of the cores in direct contact with the basalt increases with distance away from the ridge.

These ideas are shown in figure 3.11.

- When lava cools, the iron rich minerals are able to align themselves with the direction of Earth's magnetic field at the time of cooling. As the rock passes through a critical temperature called the Curie temperature (roughly 580°C), the magnetic signature of the rock will be frozen into it.
- Studies of continental lava flows indicate that Earth's magnetic field periodically reverses direction. These magnetic, or polarity, reversals are known to have happened about 170 times in the last 76 million years. The last reversal occurred about 710,000 years ago.
- Magnetic measurements in the oceans show stripes on the sea floor parallel to ridges, indicating magnetic reversals that were recorded in the crust when molten material exited along ridges and solidified to form new crust (see fig. 3.13).
- The significance of these stripes was first recognized by Vine and Matthews of Cambridge University.
- Seafloor magnetic data has been used to create maps of the age of the seafloor as illustrated in figure 3.14.
- All of the planet's sea floor was created in the last 200 million years or so.
- The magnetic field frozen into rock as it cools also points to the location of the earth's magnetic poles at the time of the rock's formation. Plots of the apparent location of the north magnetic pole as a function of time, called polar wandering curves, can be made with different suites of rocks of varying ages from different continents. The polar wandering curves produced from suites of rocks in North America and Eurasia have the same shape but do not overlap (see fig. 3.15). They converge to the present location of the pole as time decreases to the present but they diverge as time moves further into the past.
- We believe that the magnetic poles have not wandered nearly as much as typical polar wandering curves would indicate.
- The apparent polar wander with time is actually caused by the drifting of the continents and the progressive divergence of the North American and Eurasian polar wandering curves is due to the opening of the Atlantic Ocean and the gradual drift of the two continents apart.

Major Concept (VII) *Plate tectonics is a broad theory of the dynamic nature of Earth that includes the concepts of continental drift and seafloor spreading.*

Related or supporting concepts:

- The lithosphere consists of seven major, and a number of smaller, rigid plates that move with respect to one another and interact along their boundaries (table 3.2). Figure 3.16 outlines and names the largest of the lithospheric plates.
- Plates may be composed of oceanic and/or continental crust along with some underlying upper mantle material.
- There are three types of plate boundaries (fig. 3.17):
 - a. divergent boundaries where new crust is created and plates move apart (mid-ocean ridges),
 - b. convergent boundaries where oceanic lithosphere is subducted into the mantle or the edges of continents crumple as plates collide (usually marked by trenches), and
 - c. transform, or conservative, boundaries where plates slide past one another (transform faults).
- The San Andreas fault is a good example of a transform fault boundary. Shallow earthquakes occur along transform faults as the plates slide.
- Transforms offset relatively short, linear segments of ridges.

Major Concept (VIII) *Divergent plate boundaries are marked by rift zones where the lithosphere breaks apart. These occur most frequently in oceanic areas but are also seen in some continental regions.*

Related or supporting concepts:

- A series of successive divergent boundaries were responsible for the breakup of Pangaea.
- Rifting may be aided by stretching and thinning of the crust caused by the sinking of older, denser lithosphere into the mantle.
- Upward moving hot mantle material will heat the overlying lithosphere. Heating will decrease its density and cause it to arch upward, thus creating cracks that then may widen to create rifting.
- Continental rifting is currently occurring in the Great Rift Valley of Africa.
- A more advanced stage of rifting is represented by the Red Sea, where seawater has inundated the rift and a new ocean basin is forming.
- The newly created continental margin that is adjacent to the rift is called a trailing margin.
- Trailing margins, also called passive margins, are not tectonically active. They generally are not associated with earthquake or volcanic activity. They are often fairly broad and low lying with thick accumulations of sediment. A good example is the east coast of the United States.
- Most divergent boundaries are located along the axis of the mid-ocean ridge system.

Major Concept (IX) *Two plates slide past one another along transform boundaries.*

Related or supporting concepts:

- The ocean ridge system is divided into linear segments that are offset by transform faults.
- Ridge crest segments and transform faults form a continuous plate boundary.
- Differences in the age and temperature of the plate on either side of a transform boundary can create significant and rapid changes in the elevation of the seafloor (fig. 3.22).
- These changes in seafloor elevation are propagated into each plate by seafloor spreading where they are preserved as "fossil" transforms called fracture zones.
- The longest fracture zones can be up to 10,000 km (6200 mi) long.
- It is important to remember that fracture zones are not plate boundaries so there is no relative motion along them.
- The San Andreas fault is one example of a transform fault that cuts into continental lithosphere.

Major Concept (X) *Plates move toward one another along convergent plate boundaries. These may involve three types of collision; ocean-ocean, ocean-continent, or continent-continent.*

Related or supporting concepts:

- Along convergent boundaries where at least one of the plate edges is oceanic, a trench will form and oceanic lithosphere will be subducted into the mantle.
- Where two continental margins converge there will be a buckling of the crust and formation of a mountain range due to crustal thickening. Continental material is too light to be subducted but some continental material from one plate may override the continental material of the other and dramatically increase the thickness of the crust along the margin.
- In continent-continent collision there may be remnants of marine sediments and crust that have been trapped between the continents and uplifted. This is why marine fossils can sometimes be found at the tops of continental mountains such as the Alps and the Himalayas.
- Oceanic lithosphere is subducted along ocean trenches.
- The subducting plate will heat up as it descends.
- At a depth of about 100-150 km (60-100 mi) the temperature will be high enough to drive water and other volatiles out of the subducted slab. As this water is added to the surrounding mantle it will lower the melting temperature of the mantle rock and it will partially melt. This will produce a basaltic magma that will rise to the surface.
- Subduction-related volcanism may produce a line of active volcanic islands along the trench called an island arc or it may produce an active mountain range along the margin of a continent. Examples include the Aleutian Islands and the Andes

Mountains.

- Basaltic magma rising beneath a continental edge can partially melt the continental granitic rock and produce a magma of andesitic composition.
- Andesitic magmas can result in explosive volcanism such as Mount St. Helens (fig. 3.25).
- Subducting oceanic plates are also associated with earthquake activity as they bend and descend into the mantle. These dipping zones of earthquakes are called Benioff zones.
- The edge of a continent that is along a trench is called the leading margin, or sometimes an active continental margin.

Major Concept (XI) *Older crustal fragments with properties and histories different from the adjacent crustal material that join to form a continental mass are called terranes.*

Related or supporting concepts:

- Terranes may consist of pieces of island arcs systems, seamounts, seafloor plateaus, or parts of other continental land masses.
- The core of North America is thought to have formed about 1.8 billion years ago from four or five terranes.
- Alaska, the west coast, and parts of Canada are thought to have formed from terranes that came from a southerly direction about 70 million years ago.
- The east coast appears to have originated near an island arc system that came from the east.
- Roughly 25 percent of North America seems to consist of terranes. Take a look at figure 3.26 for an idea of where these are and what type of material they are.
- India is considered to be a single large terrane that migrated from high southern latitudes to impact with Eurasia to create the Himalayas.

Major Concept (XII) *The rate of plate motion is relatively slow on human terms but very fast in geological terms.*

Related or supporting concepts:

- Spreading rates vary between about 1 and 20 cm (0.4-8 in)/year.
- The average spreading rate is about 5 cm (2 in)/year.
- Although this rate seems relatively slow, there is so much time available that the plates can move great distances. In 200 million years the Pacific Ocean basin has opened and the Atlantic has appeared in even less time.
- Spreading rate has a major effect on the cross-sectional shape or morphology of spreading centers.

- At slow spreading rates, ridges typically have steep, rugged profiles with deep central rift valleys along their axis. A good example would be the Mid-Atlantic ridge.
- At fast spreading rates the flanks of the spreading center will slope more gently, they will be smoother, and there will often not be a central rift valley at all. It is common to call these divergent boundaries rises rather than ridges. An example would be the East Pacific Rise.
- Actual spreading is not a continuous process but rather occurs sporadically.
- Iceland affords us with an opportunity to examine spreading along an oceanic ridge. It is the only major island lying on top of a ridge.

Major Concept (XIII) *Hot spots are deeply rooted sources of hot, upward moving mantle material that appear to remain fixed in location for long periods of time independent of the movement of the plates above them.*

Related or supporting concepts:

- There are about forty known hot spots scattered around the globe. Some are located in continental regions while others are in ocean basins. Examples include Yellowstone National Park, Iceland, the Hawaiian Islands, and the Society Islands (Tahiti).
- The location of a specific hot spot seems to remain fixed during its life span.
- The life span of a hot spot seems to be on the order of 200 million years.
- As an oceanic plate moves over a hot spot it will create a series of active volcanoes, with the youngest directly over the hot spot and age increasing with distance away from it (see fig. 3.28). A classic example of this is the Hawaiian Island and seamount chain. The newest addition is an active seamount called Loihi about 45 km east of Hawaii. At its current rate of growth it should become an island in 50,000 to 100,000 years.
- Tracing the direction of seamount chains created at hot spots gives the absolute direction of plate motion. We know that the Pacific plate has moved in a northwest direction for the past 40 million years. Prior to that, it moved in a more northerly direction. Evidence for this comes from the Emperor Seamount Chain that joins the Hawaiian chain at an angle just west of Midway Island.
- It is very likely that in the 4.5 billion year history of Earth the continents have combined and fragmented several times. One suggestion is that there is a roughly 500 million year cycle that brings the continents back together into a giant landmass and fragments them again.
- A single landmass would collect a great deal of heat from below. This would cause the land to rise and sea level to fall. As this mass fragmented, the resultant small continents would cool rapidly, subside, and sea level would rise to cover low-lying continental regions.

Major Concept (XIV) *The continents were once joined in a single massive landmass called*

Pangaea. Roughly 200 million years ago Pangaea began to break apart to eventually produce the continents we see today.

Related or supporting concepts:

- The progressive change in relative position of the continents is illustrated in figure 3.29.
- In the early Triassic, when the first mammals and dinosaurs appeared, the continents were joined in a single landmass called Pangaea. There was a single large ocean called Panthalassa and a small sea called the Tethys.
- Roughly 200 million years ago Pangaea began to fragment into two large pieces, Laurasia and Gondwanaland, and the South Indian Ocean began to form between them.
- Shortly after the initial breakup India began to drift northward toward its eventual collision with Asia to form the Himalayan mountains.
- By about 150 million years ago Laurasia and Gondwana were separated by a narrow sea that would grow to become the Atlantic Ocean.
- Africa and South America began to split about 135 million years ago and fully separated about 65 million years ago.
- During the last 16 million years North America completely separated from Eurasia, Greenland moved away from Europe, North and South America united, and Australia separated from Antarctica.
- The Alps were formed by the collision of Italy and Europe.
- Arabia moved away from Africa about 20 million years ago to form the Gulf of Aden and ongoing rifting continues to open the Red Sea.

Major Concept (XV) *The major framework of plate tectonics has been developed but there are still countless new areas of exciting research to explore. Current research projects continue to teach us more about the planet from physical, chemical, and biological perspectives.*

Related or supporting concepts:

- The Ocean Drilling Program (ODP) began in 1983.
- Drilling operations in the ocean basins currently are conducted by the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES), a consortium of research institutions that was formed in 1985. This project uses the ship *JOIDES Resolution* as a drilling platform (refer back to fig. 1.18b).
- The *JOIDES Resolution* has visited all of the world's oceans.
- The active tectonics of the mid-ocean ridges continue to be studied using both manned and unmanned submersibles.
- One of the most interesting discoveries of expeditions to mid-ocean ridges was the presence of large communities of organisms such as tube worms and clams

surrounding areas where hydrothermal vents occur.

- Some vents discharge clear water as cool as 30°C. "White smokers" discharge milky water at temperatures of 200 to 330°C. "Black smokers" release jets of sulfur-blackened water at temperatures of 300 to 400°C.
- Hydrothermal activity is thought to continue for years to decades at individual sites but rapid changes in temperature and discharge rate have been observed over periods of days to seconds.
- Long-wavelength thermal radiation that cannot be detected by the human eye is emitted by vents. This is called "vent glow."
- Vent waters can contain high concentrations of metals such as lead, cobalt, zinc, and silver that precipitate out when they encounter the cold bottom water of the sea floor. Sulfide deposits are sometimes precipitated at vents.
- A massive hydrothermal discharge, nicknamed a "megaplume," was discovered over the Juan de Fuca Ridge in 1986. This megaplume consisted of about 100 million cubic meters of warm water that had risen to about 1000 meters above the ridge.
- The ocean basins are so vast that there are large regions that remain essentially unexplored.
- As our ability to monitor seafloor phenomena increases with more sophisticated instruments, we will undoubtedly continue to discover new things.

Key Terms and Related Major Concepts

At the back of the chapter in your book there are a number of key terms. You should be able to find the following terms referenced in the major concept indicated in parentheses.

seismic wave(I)	basalt(II)	spreading center(V)
P-waves(I)	lithosphere(III)	subduction zone(V)
S-waves(I)	asthenosphere(III)	polarity reversal(VI)
inner core(II)	Gondwanaland(IV, XIII)	plate tectonics(VII)
outer core(II)	continental drift(IV)	transform fault(VII)
mantle(II)	Pangaea(IV, XIII)	trailing margin(VIII)
crust(II)	Laurasia(IV, XIII)	leading margin(X)
density(II)	convection cell(V)	terrane(XI)
Moho(II)	seafloor spreading(V)	hot spot(XIII)
granite(II)	fracture zone(IX)	hydrothermal vent(XV)
	transform fault(VII)	

Test Your Understanding With The Following Questions:

FILL IN THE BLANK

1. The boundary between the crust and the mantle is called the _____.

2. The outer core behaves like a _____.
3. The _____ consists of a number of rigid plates.
4. Alfred Wegener was trained as a _____.
5. The age of marine sediment gets _____ as you move away from ridge crests.
6. Segments of ridge crest are offset by _____ by _____.
7. Edges of continents closest to spreading centers are called _____ margins.
8. Crustal fragments with properties and a history distinct from adjoining fragments are called _____.
9. Some people have suggested that the continents fragment and come back together in a cyclical process that takes about _____ million years.
10. Large communities of organisms have been discovered on ridge crests in the vicinity of _____.

TRUE - FALSE

1. P-waves are able to move through all states of matter: solid, liquid, and gases.
2. Continental rocks are primarily dense, basalt-type rocks.
3. The plates are driven by forces caused by Earth's rotation.
4. The concept of continental drift was proposed before seafloor spreading.
5. One of the most powerful indications of seafloor spreading is the presence of magnetic stripes.
6. The magnetic field of Earth reverses about every 10 million years.
7. The oldest oceanic crust is about 180 million years old.
8. When two continents collide there is no subduction of continental lithosphere.
9. The danger of a disaster due to an earthquake has been lessened dramatically by our ability to predict their occurrence.
10. The same volume of material created at ridges is destroyed at trenches.

MULTIPLE CHOICE

1. The largest region of Earth in terms of volume is the:
 - a. crust
 - b. mantle
 - c. outer core
 - d. inner core
 - e. lithosphere
2. The first person to suggest that southern continents were once joined in a single landmass was:

- a. Francis Bacon
 - b. Alfred Wegener
 - c. Frank Taylor
 - d. Edward Suess
 - e. Harold Jeffreys
3. About 250 million years ago there was a single landmass we call:
- a. Laurasia
 - b. Panthalassa
 - c. Pangaea
 - d. Gondwanaland
 - e. Tethys
4. North America was formerly a part of:
- a. Laurasia
 - b. Gondwanaland
 - c. Pangaea
 - d. a and c
 - e. b and c
5. Among the evidence Wegener used to support his ideas was:
- a. similar old mountain ranges on different continents
 - b. similar fossils older than 150 million years on different continents
 - c. the fit of continental coastlines
 - d. all of the above
 - e. b and c
6. Possible plate driving mechanisms include
- a. convection cells
 - b. tidal forces
 - c. rotational forces
 - d. gravitational forces acting at trenches and ridges
 - e. a and d
7. Spreading rates for plates are on the order of:
- a. 1 - 20 cm/yr
 - b. 1 - 10 mm/yr
 - c. 1 - 10 km/yr
 - d. 20 - 30 cm/yr
 - e. 40 - 50 mm/yr
8. Fast spreading centers generally have:
- a. no deep central rift valley
 - b. more gently sloping flanks
 - c. more seismicity
 - d. all of the above
 - e. a and b
9. The life span of a hot spot is thought to be about _____ years.
- a. 20 million

- b. 200 million
 - c. 1 billion
 - d. 1 million
 - e. 100,000
10. A good example of a hot spot is:
- a. Hawaii
 - b. Iceland
 - c. Yellowstone
 - d. Tahiti
 - e. all of the above

Answer Key for 'Key Terms' and 'Test Your Understanding'

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- | | |
|------------------|------------------------|
| 1. Moho | 6. transform faults |
| 2. liquid | 7. trailing |
| 3. lithosphere | 8. terranes |
| 4. meteorologist | 9. 500 |
| 5. older | 10. hydrothermal vents |

TRUE - FALSE

1.T 2.F 3.F 4.T 5.T 6.F 7.T 8.T 9.F 10.T

MULTIPLE CHOICE

1.b 2.d 3.c 4.d 5.d 6.e 7.a 8.e 9.b 10.e