CHAPTER 3 PLATE TECTONICS

Objectives

1. To define the gross internal structure of Earth.
2. To understand that the outermost part of Earth consists of a number of rigid plates, the lithosphere, which move with respect to one another on top of the plastic asthenosphere.
3. There are a number of dynamic physical processes that occur on the sea floor including the formation of new sea floor at ocean ridges and the destruction of old sea floor at ocean trenches.

Key Concepts

Major Concept (I) *Earth can be divided into four major layers: the inner core, the outer core, the mantle, and the crust.*

Related or supporting concepts:

- Densities in the interior of Earth must be very high since the average density of Earth is almost twice as great as the average density of the crust.
- The interior must consist of roughly spherical homogeneous layers since Earth doesn't wobble much as it rotates and the value of gravity over the surface is nearly constant.
- Much of what we know comes from the study of earthquake waves as they pass through Earth. There are two basic kinds of Earthquake waves: P-waves that compress the rock as they pass, and S-waves that shear the rock. P-waves can pass through any material, while S-waves can only pass through solids. Take a look at figure 3.2 for the different particle motion in P- and S-waves.
- We can infer that the outer core behaves like a liquid because S-waves cannot pass through it.
- As earthquake waves encounter boundaries in Earth their paths are refracted or bent. In addition, the velocity at which they travel will change as they move deeper into Earth and as they pass from one layer to another (fig. 3.4).
- Data recorded on stations all over the world from thousands of earthquakes have given us a clearer picture of the deep structure of Earth through a process called seismic tomography.
- It appears as if the boundary between the core and the mantle is rough with peaks and valleys. It also appears as if slabs of subducted oceanic crust that have not yet completely melted can be identified deep in the mantle.
- The inner core has the following characteristics:
  a. it forms Earth's center,
  b. its radius is 1222 km (759 mi),
  c. its temperature is between 4000°–5500°C,
  d. it is nearly five times as dense as granite,
  e. it is composed of iron with lesser amounts of nickel, sulfur, and oxygen,
  f. it is solid, and
  g. it rotates about 1° per year faster than the mantle.
- The outer core has the following characteristics:
  a. it is 2258 km (1402 mi) thick (the lower 700 km [435 mi] is a transition zone from the inner core),
  b. its temperature is about 3200°C,
  c. it has the same composition as the inner core, and
  d. it behaves like a liquid although as much as 30% of it may consist of suspended crystals, and
  e. its fluid motion moves at a speed that is thought to be on the order of kilometers per year.
- The mantle has the following characteristics:
  a. it is about 2866 km (1780 mi) thick,
  b. its temperature varies from about 1100°C to 3200°C from top to bottom,
  c. it is composed of magnesium and iron silicates,

d. the shallow mantle material is rigid,
e. there is convection in the mantle with movement on the order of centimeters per year, and
f. it comprises about 70% of Earth's volume.

- The crust has the following characteristics:
  a. there are two types; continental and oceanic,
  b. continental crust has an average thickness of about 40 km (25 mi),
  c. continental crust consists primarily of granite,
  d. oceanic crust is about 7 km (4.3 mi) thick,
  e. oceanic crust consists primarily of basalt, and
  f. both types of crust behave rigidly.

Major Concept (II)

The outermost part of Earth can be divided into layers in two different ways. A sudden change in the speed of earthquake waves distinguishes the crust from the mantle. A change in the way Earth responds to applied forces from a rigid response to a plastic, or deformable, response distinguishes the lithosphere from the asthenosphere.

Related or supporting concepts:

- Earth's crust is very different in oceanic and continental regions. Oceanic crust is about 7 km (4 mi) thick, basaltic in composition (rich in iron and magnesium), and has an average density of about 3.0 g/cm^3. Continental crust has an average thickness of about 40 km (25 mi), is granitic (rich in aluminum and magnesium silicate), and has an average density of about 2.7 g/cm^3.
- The boundary between the crust and the mantle is called the Moho.
- The lithosphere consists of the crust and the uppermost part of the mantle that is fused to the crust and moves rigidly with it.
- The oceanic lithosphere (lithosphere capped by oceanic crust) increases in thickness with increasing age of the seafloor until it reaches a maximum thickness of about 100 km (62 mi) when the seafloor is about 80 million years old.
- Continental lithosphere (lithosphere capped by continental crust) varies in thickness from about 100 km (62 mi) beneath the young marginal edges of the continents to about 150 km (93 mi) beneath old continental crust (fig. 3.6).
- Beneath the lithosphere is a region of the mantle that behaves plastically and will flow if forces are applied to it. This is the asthenosphere. The top of the asthenosphere (the base of the lithosphere) corresponds to the depth at which the mantle reaches a temperature of about 650°C +/- 100°C. It extends to a depth of about 350 km (217 mi).
- The lithosphere is less dense than the asthenosphere and floats on top of it.
- The remainder of the mantle beneath the asthenosphere is called the mesosphere.

Major Concept (III)

Even though there are differences in the thickness and density of the crust, the pressure exerted on the mantle by the crust remains constant at some depth because of isostasy.

Related or supporting concepts:

- The pressure exerted on the mantle at some constant depth in continental and oceanic regions is the same because the weight of the thick continental crust is the same as the weight of the thin oceanic crust plus the mantle down to the depth of the base of the continental crust (fig. 3.7).
- If material is removed from the surface of the Earth by the erosion of rock or the melting of ice, that area of the crust will rise. Similarly, the addition of material to the surface by volcanism will cause the crust to sink.
- The deformable asthenosphere provides buoyant support for the overlying lithosphere.

Major Concept (IV) *The configuration of the continents changes through geologic time. This movement of the continents is called continental drift.*

Related or supporting concepts:

- Early observations of the apparent fit of South America and Africa were made by:
    a. Francis Bacon, English (1561–1626),
    b. George Buffon, French (1707–88),
    c. Alexander von Humboldt, German (1769–1859), and
    d. Antonio Snyder, American, in the 1850s, said that the Atlantic Ocean had formed when a single great landmass was split by volcanic activity.
- Between 1885 and 1909 Edward Suess, Austria, proposed that the southern continents had been joined in a single great continent he called Gondwanaland. Suess believed that parts of Gondwanaland had sunk to form the oceans we see today separating the southern continents.
- Around the turn of the century, Alfred Wegener and Frank Taylor simultaneously proposed the theory of continental drift. Taylor later stopped pursuing the idea.
- Wegener suggested that roughly 200 million years ago the continents were joined in a single great landmass called Pangaea.
- Pangaea later separated into a northern continent called Laurasia and a southern continent called Gondwanaland. Laurasia included what we now recognize as North America and Eurasia while Gondwanaland was comprised of Africa, South America, India, Australia, and Antarctica (take a look at fig. 3.8).
- The evidence Wegener used to support this theory included:
    a. the visual fit of continental coastlines such as the west coast of Africa and the east coast of South America,
    b. the rejoining of old mountain chains on different continents after they are fit together,
    c. the rejoining of rock formations having the same age and chemistry on different continents after they are fit back together, and
    d. the observation that old fossils from different continents are from similar organisms while young fossils are quite different.
- Wegener's ideas were generally not accepted because he could not suggest a driving mechanism that could move the continents through the oceanic basaltic crust.

Major Concept (V) *The sea floor is not a static environment but is in motion as new sea floor is created at oceanic ridges and an equal volume is destroyed at deep trenches.*

Related or supporting concepts:

- The mantle is a dynamic region within Earth. Hot mantle material rises beneath the lithosphere, spreading out under its base and cooling. As it cools, it increases in density and sinks once more to complete a cycle called a mantle convection cell.
- There are two proposed models of mantle convection:
    a. whole-mantle convection in which large convection cells cycle material from the core-mantle boundary to the crust-mantle boundary (Moho), and
    b. a model involving two layers of convection, one confined to the upper mantle above a depth of 700 km (435 mi), and the other confined to the lower mantle.
- Sea floor volcanism is caused when the hot rising mantle material, or magma, emerges through breaks in the overlying oceanic crust. The most impressive example of this in terms of physical size occurs along the oceanic ridges and rises.
- The ocean ridges and rises form a sinuous sea floor mountain range that extends for 65,000 km (40,000 mi) through all of the ocean basins. They rise 2–3 km (1.2–1.9 mi) above the adjacent sea floor and are typically from 1000–3000 km (600–1800 mi) wide.
- Ridges have steep, rugged sides and are relatively narrow while rises have gentle, broad sides.
- Ridges have central rift valleys that are 20–50 km (12.5–31 mi) wide and 50–3000 m (165–9850 ft) deep. These rift valleys are volcanically and seismically active.

- Rises do not have a central valley. Their crest is marked by an elongate, volcanically active peak. Rises are also seismically active.
- Along the axes of both ridges and rises the volcanically active zone is about 2 km (1.2 mi) wide.
- Figure 3.10 is a good cross section through an ocean basin illustrating the major features of sea floor spreading.
- Magma extruded onto the sea floor at ridges, or spreading centers, solidifies and attaches itself to the edges of the broken crust to create new sea floor.
- In order for Earth to maintain a constant surface area and constant mass of mantle material, an amount of crust equal to that created at spreading centers must be simultaneously removed from the sea floor and returned to the mantle. This occurs as old oceanic crust is subducted into the mantle at deep-ocean trenches.
- Trenches are found primarily in the Pacific Ocean. They are rare in the Atlantic and Indian oceans.
- Trenches extend to depths that range from 6000 to 11,000 m.
- Harry Hess first proposed the idea of sea floor spreading in the early 1960s.
- The evidence that led scientists to recognize sea floor spreading included
    a. the bathymetry of the seafloor with vast mountain chains and deep trenches (see fig. 3.9),
    b. the occurrence of shallow earthquakes tracing the length of the oceanic ridge system and dipping zones of earthquakes extending into the mantle near trenches (see fig. 3.11),
    c. the increase in heat flow through the oceanic crust as you move closer to spreading centers (see fig. 3.13),
    d. radiometric dating of the oceanic crust indicated that the ocean basins are less than 200 million years old,
    e. drilling of oceanic sediments revealed that their thickness and age increase away from the ridge system (see fig. 3.16), and
    f. the presence of magnetic stripes in the sea floor parallel to ridges caused by reversals of the Earth's magnetic field (see figs. 3.18–3.20).

Major Concept (VI)

The concepts of continental drift and sea floor spreading have been combined to form a single unified theory of the dynamic behavior of Earth called "plate tectonics."

Related or supporting concepts:

- Earth's lithosphere is fragmented into a number of rigid segments called plates.
- There are seven major lithospheric plates (Pacific, Eurasian, African, Australian, North American, South American, and Antarctic) as well as a number of minor ones for a total of about 13 plates. These are shown in figure 3.22 in the text. The largest of these is the Pacific plate.
- Each lithospheric plate may include oceanic and/or continental crust.
- The boundaries of these plates are outlined by the global pattern of earthquakes that occur along their edges as they move and interact with one another.
- There are three types of plate boundaries (fig. 3.23):
    a. divergent boundaries,
    b. convergent boundaries, and
    c. conservative (or transform fault) boundaries.
- Divergent plate boundaries:
    a. are areas where plates move away from each other,
    b. are regions where mantle material comes upward to solidify and form new crust,
    c. are marked by spreading centers in ocean basins, and
    d. can occur on land, as in the Great Rift Valley of Africa (fig. 3.25), and may break apart continents to form new ocean basins (as is occurring in the Red Sea).
- A cross section through a typical ridge is shown in figure 3.28. There are four basic layers in the oceanic lithosphere:
    a. layer one is sediment that increases in thickness away from the ridge,
    b. layer two consists of rapidly cooled, glassy basalt underlain by a sequence of slower cooling vertical basalt dikes,

c. layer three is a very slowly cooled rock of basalt composition called gabbro, and
d. layer four which is a rock called peridotite making up the rigid upper mantle.

- Convergent plate boundaries:
  a. occur when the edges of two plates collide (see fig. 3.31),
  b. are marked by deep-ocean trenches whenever at least one of the plate edges is composed of dense oceanic crust that can be subducted into the mantle, and
  c. result in a dramatic thickening of the crust when both plate edges are composed of buoyant continental crust and neither can be dragged into the mantle.
- Volcanism occurs as the subducted oceanic plate partially melts. This volcanism creates active island arcs and volcanic mountain ranges along continental coasts. The chemistry of this volcanism is radically different from oceanic ridges and tends to be explosive.
- Volcanism along convergent boundaries creates andesitic volcanoes like the Andes Mountains or the Cascade Mountains, including Mount St. Helens (see fig. 3.33).
- Conservative plate boundaries (figs. 3.29 and 3.30):
  a. are often called transform faults (a familiar example is the San Andreas Fault),
  b. are boundaries where plates slide past one another with no creation or destruction of lithosphere, and
  c. typically offset segments of ridge crest.

Major Concept (VII)

There are two types of continental margins: trailing margins are closest to the divergent plate boundary, and leading margins are closest to the convergent plate boundary.

Related or supporting concepts:

- Trailing margins are also known as passive margins because they are not plate boundaries and they are tectonically passive.
- Trailing margins are welded to the adjacent oceanic crust.
- Trailing margins are often quite broad with thick wedges of sediment that accumulate at their base in the continental rise.
- The cooling, contracting, and thickening of the oceanic lithosphere combined with the weight of the sediment wedge, help to depress trailing margins and cause them to subside with time.
- Trailing margins are modified chiefly by erosion and deposition. Reef-building organisms can also modify them.
- Leading margins are also known as active margins because they are plate boundaries and they are tectonically active.
- Leading margins move with the plate toward convergent boundaries.
- When leading margins reach the convergent boundary tectonic processes modify them.
- Leading margins at trenches are typically narrow with no thick accumulation of sediment on the shelf.
- Subducted oceanic crust beneath leading continental margins can melt and rise to the surface, producing volcanically active mountain chains along the edge of the continent. A good example of this is the Andes Mountains on the west coast of South America.
- When two leading margins collide they crumple the edges of the continents and form mountain ranges such as the Himalayas and the Alps.

Major Concept (VIII)

Many different forces act on the plates and the exact driving mechanism(s) of the plates is (are) still not fully understood. Two of the important forces acting to enhance motion of the plates are believed to be the gravitational pull of subducted lithosphere on the rest of the plate, and gravitational sliding at the ridge crest, which pushes the rest of the plate.

Related or supporting concepts:

- As oceanic lithosphere moves away from a spreading center:
  a. it cools,

b. it thickens, and
c. it becomes denser.

- Old oceanic lithosphere can become dense enough to sink easily into the mantle and pull the rest of the plate along with it. This is called the slab pull force.
- Rising heat beneath spreading centers causes expansion of the oceanic lithosphere and rising of the sea floor to form the ridge system. Gravity acts to allow the plates to slide down the slope of the ridges. This is called the ridge push force.

Major Concept (IX)

Earth's tectonic plates have moved great distances and at varying rates throughout much of the geologic past. Many geologic features, and some new techniques such as assessing the ancient or paleo-magnetic patterns locked in rocks as they cool, can help us to decipher the history and behavior of the plates.

Related or supporting concepts:

- The sea floor is slowly moving away from the ridge (in both directions) at rates that range from about 1–20 cm (0.4–8 in) per year but are generally between 2–10 cm (0.8–4 in) per year. The average rate is about 5 cm (2 in) per year. This is roughly the rate at which fingernails grow.
- Although the rates seem trivial, at a rate of 1.6 cm (0.6 in) per year the lithosphere could move roughly 3200 km (2000 mi) in 200 million years. In an average lifetime (about 75 years) a plate moving at 5 cm/yr (the average rate) would travel 3.75 m (12.3 ft), or about the length of a car.
- Spreading rates vary from ridge to ridge from ‘slowly’ spreading ridges with steeply sloping sides such as the Mid-Atlantic Ridge (2.5–3 cm/yr) to ‘rapidly’ spreading systems with gentle slopes such as the East Pacific Rise (8–13 cm/yr).
- A logical inference would be that spreading rates, and pulses of spreading activity were also variable in the geologic past. Evidence from ancient rocks indicates that crustal plates existed as long as 3.5 billion years ago and moved at an average rate of about 1.7 cm/yr.
- Iceland is one locality where we can observe spreading activity on land.
- Spreading rates can now be measured directly by satellite using the Global Positioning System (GPS) discussed in chapter 1.
- Some forty or so areas of spatially fixed, long-term volcanic activity have been identified on Earth, and are called hot spots (fig. 3.34).
- Hot spot magmas change composition indicating that they may originate at different source depths in the mantle. The life span of a typical hot spot is about 100 million years. They appear to be in relatively the same positions with respect to the moving plates for their lifetimes.
- Hot spots such as the one responsible for the Hawaiian Islands, not only trace out a pattern indicating plate movement over them, they also produce a chain of volcanic features that are youngest at the hot spot, and grow older, inactive, and colder/denser away from the fixed source (see fig. 3.35).
- The products of hot spots include seamounts, platforms, plateaus, and transverse ridges. These are now used to trace and reconstruct the opening of the ocean basins, and broad changes in plate motion over time.

Major Concept (X)

When rocks cool from molten magmas, they lock in the direction and intensity of Earth’s magnetic field within certain iron-rich minerals.

Related or supporting concepts:

- Magnetic rocks of different ages on the same continent show different magnetic north pole positions (see fig. 3.21)! This suggests that either the north magnetic pole has wandered around over geologic time, or that the continents themselves have moved in relation to the pole between the times the rocks were created and cooled.
- The best evidence today links the magnetic north pole quite closely with the rotational pole of the Earth, which scientists think has not changed or even wobbled too far from its present position.

- Assuming the continents have moved rather than the pole, we can quite nicely explain different deposits from very different climates existing today in parts of the globe where they could never form. Moreover, the plates slide neatly back along their paths into Pangaea, Gondwanaland, and Laurasia.
- These same lines of evidence can be used to attempt to trace plate motions back billions of years.

Major Concept (XI) *All of the evidence we have examined indicates the last great super continent of Pangaea ("all lands") began to tear apart about 200 million years ago, with the formation of many new plate boundaries. With this breakup, the rifting, subduction, collision, and mountain building continued to produce the configurations of continents and oceans we see today.*

Related or supporting concepts:

- Since there is no reason to believe Earth's heat engine will stop, we can predict the future motions and possible configurations of continents and oceans.
- We are presently using all of the geological features and techniques to decipher plate motions hundreds of millions of years to possibly billions of years before the breakup of Pangaea. As most sea floor is recycled into the mantle, geoscientists must concentrate on the ancient rocks of the continents to continue this story.
- Six major continents are recognized from the Paleozoic era: Gondwana, Baltica, Laurussia, Siberia, China, and Kazakhstania. Study the sequence in figure 3.36 carefully to review the relative motions of these crustal plates, and the distributions of oceanic areas.
- There is no reason to believe there has ever been a geologically stable geography of Earth! This fact alone makes geology an exciting detective field that spans about 4.6 billion years on an ever-changing globe.
- Recent evidences and calculations of thermal energy in Earth suggest a 500 million year cycle in major plate movement.
- North America appears to have a core that was assembled 1.8 billion years ago from several large pieces of continental crust more than 3 billion years old. These large crustal pieces are called cratons.
- Smaller crustal fragments, called terranes, with a history distinct from the cratons can be found along their margins (see fig. 3.37).

Major Concept (XII) *Hydrothermal vents with amazing communities of organisms have been found along the axis of the mid-ocean ridge system.*

Related or supporting concepts:

- A spectacular feature of rift systems is hydrothermal vent fields. Discovered almost by accident in the 1970's these areas contain unique biological ecosystems based on chemosynthesis (dependent on methane, hydrogen sulfide, or particulate sulfur-eating bacteria) rather than photosynthesis, and may also provide a rich treasure of metalliferous deposits for future mining efforts.
- Vent systems have been found both on very young sea floor along the axis of the ridge system and, more recently, as far as 15 km away from the axis of the ridge on older sea floor (as much as 15 million years old).
- The temperature of hydrothermal vents right along the axis of the ridge can be as high as 400°C and precipitate iron and sulfide-rich minerals.
- The temperature of vent fluids off the axis of the ridge is much cooler, as low as 40–75°C, and the minerals that precipitate are rich in carbonate and magnesium.

Major Concept (XIII) *The sophistication of our theories about the history of the ocean basins depends on ever-increasingly sophisticated techniques and tools with which to investigate the ocean.*

Related or supporting concepts:

- Many areas of the sea floor are currently under investigation in the Ocean Drilling Program.
- The ODP is scheduled to end in 2003 and the plan is to replace it with an even more ambitious drilling program called the Integrated Ocean Drilling Program (IODP).
- IODP will use two drill ships, the *JOIDES Resolution* and a new larger vessel, the *Chikyu*, built by Japan.
- Rift zones are exotic places to visit, as they require the use of highly sophisticated manned submersibles or remotely operated vehicles (ROV's). Project FAMOUS was one of the first joint oceanographic projects involving the U.S.A., Canada, Britain, and France. Scientific groups investigated, and mapped in detail a small portion of the Mid-Atlantic Ridge system.

Matching Key Terms with Major Concepts

At the end of the chapter in the textbook is a list of key terms. You should be able to match each of these with one of the previously listed major concepts. To test your ability, try to match the following key terms with the number (I–XIII) of the appropriate major concept identified in this section:

isostasy	lithosphere	magma
transform fault	hot spot	polar wandering curve
slab pull	divergent boundary	Laurasia
continental drift	crust	density
polar reversal	Project FAMOUS	asthenosphere
leading margin	sea floor spreading	convergent boundary
Pangaea	Gondwanaland	mantle
Moho	trailing margin	ridge push
Ocean Drilling Program	Wegener	inner core
P– & S–waves	refraction	granite
basalt	convection cell	rift zone
graben	hydrothermal vent	terrane
mesosphere	seismic tomography	craton

Test Your Recall

Answer the following questions to test your understanding

FILL IN THE BLANK

1. Shear waves will not pass through the _________________ _____________.
2. The density of the material inside Earth __________________________ with increasing depth.
3. The outermost part of Earth that moves rigidly and comprises what we call the plates is the _______________________________.
4. Changes in magnetic polarity of the sea floor create a pattern of ________________ parallel to ridges.
5. The oceanic crust is subducted into the ___________________ at oceanic ________________________.
6. Fixed sources of heat deep in the mantle that burn holes through the overlying crust and reveal the direction of motion of the plates are called _____________ _____________.
7. The theory that addressed the apparent ability of landmasses to move through the crust is called __________________________________ __________________.
8. The theory that described the creation, destruction, and mobility of the oceanic crust is called _________________________ ____________________________.

9. The broad theory that describes the dynamic nature of large segments of the lithosphere and the underlying mantle is called ________________ ____________________________.
10. New oceanic crust is created at ____________________________ plate boundaries.
11. The edge of a continent that is closest to a trench is called the _________________________ margin.
12. Scientists today would characterize the Earth as being composed of spherical ___________________.
13. The ________________ _____________ is solid, very dense, very hot, and rich in iron and nickel.
14. The largest layer of Earth is called the ____________________.
15. A ______________________ _____________ is an Earth shock wave or vibration produced by an earthquake or underground explosion.
16. When seismic waves encounter layers of different ________________, they bend or _________________.
17. The _______________________ of seismic waves changes from layer to layer.
18. Continental landmasses (crust) are formed primarily of _____________________, while oceanic crust is primarily made up of ____________________.
19. The ____________________________________ is the area of the upper mantle just below the lithosphere that behaves in a plastic fashion.
20. The ______________________ of a portion of a lithospheric plate determines its final elevation.

TRUE - FALSE

1. The asthenosphere behaves in a plastic fashion when forces are applied to it.
2. Continental crust is thicker and denser than oceanic crust.
3. When two continental margins collide, one will be subducted deep into the mantle.
4. Slow spreading centers tend to have steep, rugged sides compared to fast spreading centers.
5. Geologists have been able to directly sample sediments and the underlying oceanic crust by drilling.
6. Earth’s magnetic field periodically reverses its polarity.
7. The mantle is composed of dense, rigid material that does not deform over geologic time.
8. The largest plate on the globe is the North American plate.
9. The entire Atlantic Ocean basin is one major plate.
10. The plates are outlined by the earthquakes that occur along their boundaries.
11. The oceans are the ultimate disposal area for human wastes.
12. There are no organisms that can survive without the sun to provide energy for plant life, and therefore, organic matter as a food source for them.
13. Scientists can drill into the ocean crust to decipher the history and movement of the ocean basins.
14. Geologists cannot predict future movements of Earth’s crustal plates.
15. Most of Earth’s continents were widely separated from one another 550 million years ago.
16. There are many places on Earth that have remained in the same spot over the last 2.5 billion years.
17. The core of the North American craton, was formed by plate tectonic-like collisions between even older pieces of continental crust some 1.8 billion years ago.
18. We can't decipher ancient convergent margins or plate collisions by looking at old mountain ranges in the interior of continents.
19. Earth’s rotational pole/axis has wobbled slightly but never moved very far from its present location.
20. Hot spots and their volcanic island chains can be used to trace the movement of oceanic lithosphere.

MULTIPLE CHOICE

1. Our current models of the interior of Earth are based on
    a. observations of earthquake waves.
    b. examination of meteorites.
    c. measurements of gravity.
    d. the shape of Earth.
    e. all of the above.

2. The largest internal subdivision of Earth is the
    a. crust.
    b. mantle.
    c. outer core.
    d. inner core.
    e. lithosphere.
3. Mantle convection cells
    a. rise beneath ocean trenches.
    b. bring granite to the surface to form continents.
    c. carry mantle material upwards beneath ridges.
    d. inhibit the motion of the plates.
    e. only occur beneath continents.
4. Oceanic crust
    a. cools as it moves away from ridges.
    b. thickens away from ridges.
    c. increases in age towards ridges.
    d. a and b above.
    e. b and c above.
5. The oldest oceanic crust is roughly
    a. 2 million years old.
    b. 20 million years old.
    c. 200 million years old.
    d. 2 billion years old.
    e. none of the above.
6. Old oceanic lithosphere is destroyed at
    a. convergent plate boundaries.
    b. divergent plate boundaries.
    c. transform faults.
    d. conservative plate boundaries.
    e. hot spots.
7. Active volcanism occurs in association with
    a. trenches.
    b. hot spots.
    c. ridges.
    d. all of the above.
    e. none of the above.
8. The plates typically move at velocities of
    a. a few millimeters/yr.
    b. a few centimeters/yr.
    c. a few meters/yr.
    d. a few feet/yr.
    e. a few yards/yr.
9. Pangaea began to break apart approximately _______ years ago
    a. 50 million.
    b. 100 million.
    c. 150 million.
    d. 200 million.
    e. 250 million.
10. Evidence of the positions of the continents before Pangaea formed comes from
    a. fossils on land.
    b. magnetic data from the continents.
    c. the locations of old mountain ranges.
    d. the locations of old continental rock bodies.
    e. all of the above.
11. Project FAMOUS conducted detailed studies of

a. a portion of the Mid-Atlantic Ridge.
b. the depths of the Marianas Trench.
c. submerged seamounts in the Pacific.
d. the Red Sea.
e. the East Pacific Rise.

12. Hydrothermal vents at ridge crests
    a. expel hot water that has circulated through the crust.
    b. are often sites of dense biological communities.
    c. are areas where chemical deposits rich in metals precipitate on the sea floor.
    d. all of the above.
    e. none of the above.
13. Earth's outer core is
    a. solid.
    b. liquid.
    c. gas.
    d. iron and nickel.
    e. b and d.
14. The two seismic waves discussed in the text are body waves that travel rapidly through Earth. These two wave types are called
    a. tsunami and roller waves
    b. G– and D–waves.
    c. P– and S–waves.
    d. Rayleigh and Love waves.
    e. none of the above.
15. Continental crust has a density of _______ g/cm^3 and is about _________ km thick on the average.
    a. 3.2, 15
    b. 2.5, 25
    c. 2.0, 45
    d. 2.8, 55
    e. 3.1, 60
16. Areas where new crust is formed above rising plumes of magma are called
    a. spreading centers.
    b. subduction zones.
    c. pizzerias.
    d. cold spots.
    e. leading edges.
17. Plate tectonics is the theory of moving plates on Earth's surface. The main interactions between plates tend to be at their boundaries. The three main boundary types are
    a. divergent, congruent, and trans-American.
    b. convergent, divergent, and transparent.
    c. transform, divergent, and convergent.
    d. tangential, circumstantial, and problematical.
    e. none of the above.
18. When two continental plates collide
    a. one plate is subducted deep into the mantle.
    b. they are crumpled and deformed.
    c. one plate may override the other.
    d. oceanic sediments between them are squeezed up into the deformed zone.
    e. b, c, and d above.
19. Volcanoes at subduction zones are violent and have a composition of
    a. basalt.
    b. granite.
    c. egg whites.
    d. andesites.
    e. endocytes.

20. Hot spots produce
    a. seamounts.
    b. plateaus.
    c. guyots.
    d. a, b, and c above.
    e. none of the above.

Visual Aids: Test Your Understanding of the Figures

1. Study figures 3.17 and 3.21. How can we say that we can be relatively sure of the latitude of the crustal plates that made up Pangaea but not of their longitude?
2. Explain two consequences or deductions you can make after closely examining figure 3.16.
3. Study figure 3.22 carefully. Now close the book and draw North and South America. Label the oceans and plate boundaries just east and west of these two continents.

Study Problems

1. If an oceanic plate has a spreading rate of 5 cm/yr for 15 million years and 2 cm/yr for 10 million years, how far will it move away from the ridge in that 25 million year period of time? Express your answer in kilometers.
2. One of the more remarkable characteristics of the oceanic crust is its relative youth compared to the age of the planet. Assume that the amount of new sea floor created annually has always been a constant 2.8 km^2/yr. If the total area of sea floor is 320 million km^2, what is the average age of the oceanic crust?
3. The total length of the oceanic ridge system in all of the oceans is about 65,000 kilometers. If 2.8 km^2 of sea floor is created each year, what is the width in centimeters of the strip of new sea floor that is created along the ridge system annually?
4. From the results of problem three, what is the average spreading rate in cm/yr for a single plate?

Answer Key for Key Terms and Test Your Recall

KEY TERMS

isostasy (III)	lithosphere (II)	magma (V)
transform fault (VI)	hot spot (IX)	polar wandering curve (X)
slab pull (VIII)	divergent boundary (VI)	Laurasia (XI)
continental drift (IV)	crust (I)	density (III)
polar reversal (X)	Project FAMOUS (VII)	asthenosphere (II)
leading margin (VII)	sea floor spreading (V)	convergent boundary (VI)
Pangaea (XI)	Gondwanaland (XI)	mantle (I)
Moho (II)	trailing margin (VII)	ridge push (VIII)
Ocean Drilling Program (XIII)	Wegener (IV)	inner core (I)
P– & S–waves (I)	refraction (I)	granite (II)
basalt (II)	convection cell (V)	rift zone (VI)
graben (VI)	hydrothermal vent (XII)	terrane (XI)
mesosphere (II)	seismic tomography (I)	craton (XI)

FILL IN THE BLANK

1. outer core	2. increases	3. lithosphere
4. stripes	5. mantle, trenches	6. hot spots
7. continental drift	8. sea floor spreading	9. plate tectonics
10. divergent	11. leading	12. layers
13. inner core	14. mantle	15. seismic wave
16. density, refract	17. speed (velocity)	18. granite, basalt
19. asthenosphere	20. density	

TRUE - FALSE
1.T 2.F 3.F 4.T 5.T 6.T 7.F 8.F 9.F 10.T 11.T 12.F 13.T 14.F 15.T 16.F 17.T 18.F 19.T 20.T

MULTIPLE CHOICE
1.e 2.b 3.c 4.d 5.c 6.a 7.d 8.b 9.d 10.e 11.a 12.d 13.b 14.c 15.d 16.a 17.c 18.c 19.d 20.d

STUDY PROBLEMS
1. 950 kilometers
2. 57 million years
3. 4.3 centimeters
4. 2.15 centimeters/year