CHAPTER 3
PLATE TECTONICS

Important Concepts

1. *Plate tectonics* refers to the existence and movement of rigid lithospheric plates over the mantle's asthenosphere and relates this activity to the large-scale movement and deformation of the earth's crust.

2. *Stress* is the amount of force per unit area applied to an object. *Strain* is the deformation resulting from the applied stress. Rocks may undergo *elastic* deformation, *plastic* deformation, and finally rupture with increasing stress. *Brittle* rocks rupture prior to any plastic deformation.

3. The *lithosphere* consists of the earth's crust and the uppermost, solid portion of the mantle. It is thinnest underneath the oceans and thickest underneath the continents.

4. The *asthenosphere* lies immediately beneath the lithosphere and exists in a plastic state. The discovery of the asthenosphere overcame the major objection to the concept of continental drift.

5. The distributions of earthquakes and volcanoes are concentrated along plate boundaries.

6. The theory of plate tectonics is supported by the following lines of evidence:

   (a) The presence of parallel bands of ocean floor basalts that are symmetrically disposed about the ocean ridges and exhibit alternating magnetic polarities.

   (b) The decreasing age of seafloor basalts with increasing distance from ocean ridges.

   (c) Polar-wander curves, which indicate that the continents have moved through time relative to the earth's stationary geographic (rotational axis) poles and relative to each other.

   (d) The similarity of paleoclimatic conditions for widely separated parts of the world (for example, evidence of glaciation in parts of Australia, southern Africa, and South America that are now located in tropical latitudes).

   (e) The distribution of animal and plant fossils representing species of restricted range on widely separated continents (for example, *Mesosaurus* and *Glossopteris*, respectively, in limited areas of South America, India, and Australia).

   (f) The close fit of matching continental margins (for example, of South America and Africa).

   (g) The continuation of geologic structures from one continent to another, which are now separated by oceans (for example, the Appalachian-Caledonian mountain chain).

7. About 200 million years ago the continents were united in a single supercontinent named Pangaea.

8. The plate boundaries are of three types:

   (a) *Divergent plate boundaries*, zones where lithospheric plates move apart and new lithosphere is created from upwelling magma. Oceanic spreading ridges and continental rift zones are examples of divergent plate boundaries.

(b) *Convergent plate boundaries*, zones where the leading edges of lithospheric plates collide. In a continent-continent convergence, the margins of the colliding plates are crumpled, thickened, and deformed. In ocean-ocean convergence and in ocean-continent convergence, the leading edge of one plate is pushed (subducted) under the other and into the asthenosphere, resulting in a *subduction zone*.

(c) *Transform faults* that offset segments of a spreading ridge. The opposite sides of a transform fault belong to two different plates that are moving in opposite directions. The San Andreas fault is an example of a transform fault.

9. Subduction zones are, geologically, very active places. They are the sites of major earthquakes, copious volcanism (forming chains of volcanic islands or *island arcs*), and the accumulation of considerable amounts of sediments (derived from the erosion of the continents) in *oceanic trenches*.

10. *Hot spots* are isolated, intraplate centers of volcanic activity that may represent localized plumes of hotter mantle material arising from localized, fixed plumes of upwelling magma. When an overlying lithospheric plate slowly moves over a stationary hot spot, the result should be a string of volcanoes of differing ages with the youngest closest to the hot spot (example: the Hawaiian chain of volcanic islands).

11. Lithospheric plates typically move at an average rate of 2 to 3 centimeters per year, although plate movements at rates as high as about 10 centimeters per year have been observed.

12. Mechanisms proposed to explain the movement of lithospheric plates include the following:

(a) The plates are driven by large convection cells in the asthenosphere. The existence of these cells, however, has not been proven.

(b) The weight of the downgoing slab of lithosphere at the subduction zone pulls the rest of the trailing plate along with it.

(c) Lithospheric plates sliding off topographic highs at spreading ridges drag some asthenosphere laterally.

13. The theory of plate tectonics provides a coherent rationale for the rock cycle (see figure 3.22).

Key Terms

asthenosphere
brittle
compressive stress
continental drift
convection cell
convergent plate boundary
Curie temperature
divergent plate boundary
elastic deformation
elastic limit
hot spot
island arc
lithosphere
paleomagnetism
plastic deformation
plate tectonics
polar-wander curve
rupture
seafloor spreading
shearing stress
strain
stress
subduction zone
tectonics
tensile stress
transform fault

Multiple Choice

1. One of the first scientists to propose the hypothesis of continental drift was
    a. F. J. Vine.
    b. James Hutton.
    c. Alfred Wegener.
    d. D. H. Matthews.

2. The hypothesis of continental drift was initially rejected by most scientists because
    a. there was overwhelming evidence against it.
    b. few scientists believed it possible for the continents to move over a solid earth.
    c. the earth was considered to be too young for the continents to have moved any appreciable distance.
    d. the positions of the continents on ancient maps were the same as on modern maps.

3. The lithosphere
    a. is partly molten and plastic in consistency.
    b. was discovered by studying the behavior of seismic waves generated by earthquakes.
    c. extends to an average depth of about 300 kilometers.
    d. is thickest under the continents, thinnest beneath the oceans.

4. The asthenosphere lies entirely within
    a. the ocean ridges.
    b. the upper mantle.
    c. the lower mantle.
    d. the lithosphere.

5. The study of paleomagnetism has revealed that
    a. the earth's outer core is mostly liquid iron.
    b. drifting continents follow the earth's magnetic lines of force.
    c. earth's magnetic field has reversed many times.
    d. the rocks of the sea floor are less that 200 million years old.

6. The origin of earth's magnetic field is probably due to
    a. the presence of iron in the inner core.
    b. electric currents in the fluid outer core.
    c. magnetized minerals in the crust.
    d. ferromagnesian minerals in the mantle.

7. Ocean floor rocks on both sides of an ocean ridge show
    a. magnetization in one direction on one side of the ridge and magnetization in the opposite direction on the other side of the ridge.
    b. alternating bands of normal and reverse magnetization on both sides of the ridge.
    c. the same direction of magnetization on both sides of the ridge.
    d. no consistent pattern of magnetization.

8. Relative to continental crust, ocean floor crust is
    a. much older.
    b. slightly older.
    c. much younger.
    d. the same age.

9. About 200 million years ago, earth's landmasses were united in a single supercontinent called
    a. Pangaea.
    b. Atlantis.
    c. Gondwanaland.
    d. Eurasia.

10. The landmass that eventually split up into South America, Africa, India, Antarctica, and Australia was
    a. Laurasia.
    b. Eurasia.
    c. Gondwanaland.
    d. Oceana.

11. New lithosphere is created at
    a. convergent plate boundaries.
    b. subduction zones.
    c. transform faults.
    d. divergent plate boundaries.

12. The San Andreas fault is an example of
    a. continental rifting.
    b. a transform fault.
    c. an active subduction zone.
    d. a convergent plate boundary.

13. India
    a. formed from sediments eroded from the Himalaya Mountains.
    b. represents a section of ocean ridge raised above sea level.
    c. drifted into Asia.
    d. has always been a part of the Asian continent.

14. The Himalaya and Appalachian Mountains represent sites of sustained
    a. plate convergence.
    b. hot spot activity.
    c. continental rifting.
    d. plate divergence.

15. Island arcs are associated with
    a. hot spots.
    b. ocean-ocean convergences.
    c. continent-continent collisions.
    d. ocean-continent convergences.

16. All of the following have been used to determine the rates and directions of plate movements except
    a. polar-wander curves.
    b. seafloor spreading.
    c. mantle hot spots.
    d. earthquake locations.

17. Hot spots
    a. are usually associated with divergent plate boundaries.
    b. occur beneath ocean basins but not under continents.
    c. remain stationary as lithospheric plates move over them.
    d. interfere with the movement of lithospheric plates.

18. Lithospheric plates move at an average rate of _____ per year.
    a. 10 millimeters
    b. 12 to 15 centimeters
    c. 2 to 3 centimeters
    d. 7 to 8 kilometers

19. Plate-tectonic processes on earth have been active for at least
    a. 57 million years.
    b. 200 million years.
    c. 500 million years.
    d. 2 billion years.

20. The ages of the volcanoes comprising the Hawaiian chain of islands is consistent with
    a. a west-northwest direction of movement of the Pacific Plate over a stationary mantle hot spot.
    b. an east-southeast direction of movement of the Pacific Plate over a stationary mantle hot spot.
    c. a divergent boundary setting of the islands.
    d. an island arc produced at a convergent boundary.

Fill In the Blanks

1. _____ is the study of large-scale movement and deformation of the earth's crust.

2. The solid and rigid outermost layer of the earth is called the _____.

3. _____ stress tends to squeeze an object; _____ stress tends to pull an object apart.

4. _____ is the deformation produced in a body of matter in response to stress applied to it.

5. If a material is subjected to _____ deformation, the material will return to its original size and shape when the stress is removed.

6. A _____ material may rupture before there is any plastic deformation.

7. _____ temperature is the temperature above which a magnetic material loses its magnetism.

8. The ocean floor is made up largely of the volcanic rock known as _____.

9. At a _____ plate boundary, lithospheric plates move apart; at a _____ plate boundary, lithospheric plates move toward each other.

10. Laurasia and _____ are names given to the northern and southern portions of Pangaea, respectively.

11. Most of North America is part of the North American Plate; however, the part of California to the west side of the San Andreas fault is part of the _____ Plate.

12. Excess sea floor is consumed in _____ zones.

13. _____ cells in the asthenosphere may be a driving force behind plate tectonics.

14. The concept that rocks are constantly subject to change and that any type of rock can be transformed into another type of rock is called the _____ _____.

True or False

Indicate whether the following statements are true or false. If false, correct the statement to make it true.

_____ 1. Volcanoes and earthquakes are concentrated along the margins of lithospheric plates.

_____ 2. The discovery of the asthenosphere proved that lithospheric plates move.

_____ 3. The North American Plate is moving to the south with respect to the Pacific Plate.

_____ 4. Seafloor rocks get progressively younger the farther they are from both sides of an ocean ridge.

_____ 5. Polar-wander curves prove that the magnetic poles have meandered over the earth's surface with time.

_____ 6. The breakup of the supercontinent Pangaea began about 200 million years ago.

_____ 7. New lithosphere is created along divergent plate boundaries.

_____ 8. The opposite sides of a transform fault belong to two different plates moving in opposite directions.

_____ 9. Continental lithosphere is similar in density to that of the asthenosphere.

_____ 10. A continent-continent collision may result in increased thickness of continental crust.

Review Questions

1. What causes strain in rocks? Explain the difference between elastic and plastic strain.

2. Explain the concept of plate tectonics. How are continental drift and seafloor spreading related to it?

3. List and briefly explain the various lines of evidence in support of plate tectonics.

4. What are the three types of plate boundaries and how do they differ from each other? Draw a sketch showing the different geologic processes/products that you can expect along a subduction zone.

5. What are hot spots, and how do they help to determine rates and directions of plate movements?

Surfing the Net

An excellent review of plate tectonics (United States Geological Survey):
<http://geology.usgs.gov/publications/text/dynamic.html>

An archive of articles and data pertaining to plate tectonics:
<http://www.platetectonics.com>

Animated reconstructions and links relevant to plate tectonics (Web DoGS):
<http://www.uky.edu/ArtsSciences/Geology/webdogs/plates/reconstructions.html>

Informative and interesting historical perspective on the theory of plate tectonics:
<http://www.hartrao.ac/geodesy/Plate.html>

CHAPTER 3 ANSWER KEY

Multiple Choice

1. c
2. b
3. d
4. b (figure 3.4)
5. c
6. b
7. b
8. c
9. a
10. c (figure 3.14)
11. d
12. b
13. c
14. a
15. b
16. d
17. c
18. c
19. d
20. b

Fill In the Blanks

1. Tectonics
2. lithosphere
3. Compressive, tensile
4. Strain
5. elastic
6. brittle
7. Curie
8. basalt
9. divergent, convergent
10. Gondwanaland (figure 3.14)
11. Pacific
12. subduction
13. Convection
14. rock cycle

True or False

1. True
2. False. The discovery of the asthenosphere did not prove that lithospheric plates move; however, its discovery made the continental drift hypothesis more plausible.
3. False. The North American Plate is moving to the west with respect to the Pacific Plate (Figure 3.6).
4. False. Seafloor rocks get progressively older the farther they are from both sides of an ocean ridge.
5. False. Polar-wander curves provide a means of mapping the directions in which the continents have moved with time relative to each other and the earth's stationary magnetic poles.
6. True
7. True
8. True
9. False. Oceanic lithosphere is similar in density to that of the asthenosphere.
10. True