Chapter 2

Plate Tectonics and the Ocean Floor

Learning Objectives

The instructional objectives are performance-based and detail specific learning outcomes for Chapter 2. The test items contained in the Test Bank are keyed to the learning objectives and *Chapter in Review* at the end of the chapter. The order of the objectives mirrors the content presentation in Chapter 2.

Upon completion of this chapter, the student should be able to:

1. Restate the theory of **plate tectonics**.

2. List the evidence used by Alfred Wegener to formulate his **continental drift** theory including:
   A. continental fit, especially South America and Africa
   B. similarities in the rock sequences (age and structure) on opposite sides of ocean basins.
   C. occurrence of past glacial activity in tropical areas
   D. similar fossil distributions in continents that were once connected

3. Distinguish between Alfred Wegener's continental drift theory and the modern theory of plate tectonics. Be certain that you outline the early ideas about continental drift that are extant in the modern theory.

4. Describe the evidence that supports the current version of the theory of plate tectonics including:
   A. orientation of magnetic particles in the Earth's crust
   B. magnetic dip (function of the latitude at which the rock cooled)
   C. apparent polar wandering
   D. magnetic polarity reversals
   E. ocean floor magnetic anomalies
   F. sea floor spreading
   G. uneven heat flow in the Earth's crust
   H. worldwide earthquake distribution

5. List the features found in the following types of plate boundaries:
   A. divergent plate boundary
   B. convergent plate boundary
   C. transform plate boundary

6. Distinguish between **mantle plumes** and **hotspots**.

7. Describe how the occurrence and distribution of mantle plumes and hot spots supports the current theory of plate tectonics.

8. Illustrate the arrangement of the continents when the supercontinent Pangea existed.

9. Make predictions about continental position in the geologic future.

Overview

Chapter 2 is a discussion of the nature of Earth's crustal movements in the context of plate tectonic theory. This chapter presents a discussion of the historical development of our understanding of continental drift and how new discoveries shaped the development of current plate tectonic theory. The current knowledge of Earth's internal structure is covered, and the implications of near surface structure for plate movement is presented. Different types of plate boundaries and the types of crustal movements associated with each type of boundary are discussed. An emphasis on sea floor plate boundaries and plate movement is included in this chapter. The chapter concludes with some discussion of plate tectonic applications that include paleoceanography and predictions for future continental locations.

Headings covered in this chapter include:
Evidence for Continental Drift
- Fit of the Continents
- Matching Sequences of Rocks and Mountain Chains
- Glacial Ages and Other Climate Evidence
- Distribution of Organisms
- Objections to the Continental Drift Model

Evidence for Plate Tectonics
- Earth's Magnetic Field and Paleomagnetism
- Sea Floor Spreading and Features of the Ocean Basins
- Other Evidence from the Ocean Basins
- The Acceptance of a Theory

Earth Structure
- Chemical Composition Versus Physical Properties
- Near the Surface
- Isostatic Adjustment

Plate Boundaries
- Divergent Boundaries
- Convergent Boundaries
- Transform Boundaries

Testing the Model: Some Applications
- Mantle Plumes and Hotspots
- Seamounts and Tablemounts
- Coral Reef Development
- Detecting Plate Movement with Satellites
- The Past: Paleoceanography
- The Future: Some Bold Predictions

Special Features:
- *Box 2.1: Research Methods in Oceanography: Do Sea Turtles (and Other Animals) Use Earth's Magnetic Field for Navigation?*

Teacher's Resources

There is a wide assortment of good films/videos on plate tectonics, including:

- Boundary Creation (NOAA), 26 minutes
- Continental Drift: The Theory of Plate Tectonics (Encyclopedia Britannica), 21 minutes
- Continental Drift and Plate Tectonics (Tanya Atwater/University of California Santa Barbara), 19 minutes
- Continents Adrift (American Educational), 15 minutes
- Earth Revealed: The Restless Planet (Program #2) (The Annenberg/CPB Collection), 30 minutes
- Earth Revealed: Plate Dynamics (Program #6) (The Annenberg/CPB Collection), 30 minutes
- Not So Solid Earth (Time-Life Film and Video), 30 minutes
- Restless Earth, Plate Tectonics (Indiana University), 100 minutes (two 50-minute filmstrip reels)
- This Land (Shell Oil), 41 minutes
- Volcano Surtsey (North Shore News), 26 minutes

CD-ROMs
- The Theory of Plate Tectonics (Tasa Graphic Arts, Inc.) (introductory college level)
- Plate Tectonics and How the Earth Works (Tasa Graphic Arts, Inc.) (advanced college level)
- Understanding Earth (Videodiscovery, Inc.)

Answers to Review Questions

1. When did the supercontinent of Pangea exist? What was the ocean called that surrounded the supercontinent?

Pangea existed about 200 million years ago. The single largest ocean surrounding Pangea was Panthalassa (refer to Figures 2.5 (a) and (b), Ice Age on Pangea).

2. Cite the lines of evidence Alfred Wegener used to support his idea of continental drift. Why did scientists doubt that continents drifted?

Alfred Wegner used the following evidence to support continental drift:
- ✓ The fit of the continental margins across ocean basins
- ✓ Matching rock sequences and mountain ranges on different continents
- ✓ Climate evidence such as glacial deposits in areas that are now close to the Equator
- ✓ The distribution of organisms across continents that are separated by oceans that these organisms could not have crossed

Although the evidence in support of continental drift seems compelling, scientists in Wegener's time rejected the idea of continental drift because the mechanisms Wegener proposed as driving continental movement seemed too far-fetched to be plausible. Some scientists felt that Wegener's proposal ran contrary to the understanding of the laws of physics in the early 20th century. When sea floor spreading data became available in the 1950s and 1960s, Wegener's ideas about continental movement were combined with these data to provide a more current model that explained crustal movement.

3. Describe Earth's magnetic field, including how it has changed through time.

Earth's magnetic field resembles the magnetic field produced by a large bar magnet. Bar magnets have ends that are oppositely charged. The magnet ends are usually designated by "+" and "–" or "N" (for north) and "S" (for south). This opposite polarity causes magnetic objects to align parallel to the magnetic field produced by the bar magnet. Although Earth does not actually have a bar magnet inside, it behaves as if it did. Invisible lines of magnetic force originating from within Earth travel through the planet and out into space (see Figure 2.7, Nature of Earth's magnetic field).

The strength of Earth's magnetic field has changed through time (on the geologic time scale). Additionally, Earth has experienced many dozens of magnetic field polarity reversals during the last 100 million years.

4. Describe how sea turtles use Earth's magnetic field for navigation.

Research in the field of magnetoreception, the study of an animal's ability to sense magnetic fields, suggests that sea turtles and some marine mammals may use Earth's magnetic field for navigation. It has been demonstrated that hatchling sea turtles can distinguish between different magnetic inclination angles. In effect, this allows sea turtles to sense latitude. Recent research indicates that sea turtles can also sense magnetic field intensity, a rough indication of latitude. Using the ability to sense magnetic field intensity and magnetic inclination, the sea turtles can construct a magnetic map with grid coordinates that can be used for navigation. A sea turtle can use the magnetic map to determine its location and navigate to a tiny island that is hundreds or thousands of miles away for breeding. For more information refer to Box 2.1: *How Do Sea Turtles (and Other Animals) Use Earth's Magnetic Field for Navigation?*

5. Why is the pattern of alternating reversals of Earth's magnetic field as recorded in sea floor rocks such an important piece of evidence for advancing plate tectonics?

The alternating (or striped pattern) reversals of Earth's magnetic field recorded in sea floor rocks could be created when newly formed rocks at the mid-ocean ridges are magnetized and align with the direction of Earth's magnetic field at the time of their formation. As these rocks move slowly away from the crest of the mid-ocean ridge, periodic magnetic pole reversals produce rocks with different magnetic orientation, recording polarity changes in sea floor rocks. This produces a pattern of magnetic polarity stripes in the sea floor that are symmetrical on either side of the mid-ocean ridge (refer to Figure 2.12). This pattern strongly supports the existence of sea floor spreading at mid-ocean ridges.

6. Describe sea floor spreading and why it is an important piece of evidence for advancing plate tectonics.

The age relationships and pattern of symmetric stripes on the sea floor with respect to the axis of the mid-ocean ridge indicate that sea floor spreading occurs along the mid-ocean ridge. With sea floor spreading as a mechanism, many of the arguments against continental drift could no longer be supported, so it helped to advance the development of continental drift and the formation of plate tectonic theory.

7. Describe the general relationships that exist among the distance from spreading centers, heat flow, age of ocean crustal rock, and ocean depth.

With increasing distance in either direction from the spreading center, the amount of heat flowing through Earth's surface decreases, and the age of the ocean floor increases along with ocean depth.

8. Why does a map of worldwide earthquakes closely match the locations of worldwide plate boundaries?

Plate boundaries are locations where plates interact. Earthquakes frequently occur in areas where convergent or transform plate movements occur. There is a high correlation between worldwide earthquake location and plate boundaries.

9. Most lithospheric plates contain both oceanic- and continental-type crust. Use plate boundaries to explain why this is true.

Plate boundaries rarely follow continental margins, so most large plates contain a continent (continental crust) as well as a large area of ocean floor (oceanic crust).

10. Describe the differences between oceanic ridges and oceanic rises. Include in your answer why these differences exist.

Spreading rates (the total widening rate of an ocean basin resulting from the motion of *both* plates away from the spreading center) vary along the mid-ocean ridge and profoundly affect the slope of the mountain range. The faster the spreading rate, the broader the mountain range associated with the spreading center. The rapidly spreading and gently sloping portions of the mid-ocean ridge are called oceanic rises. The slower and steeper-sloped areas of the mid-ocean ridge are called oceanic ridges. Oceanic ridges and oceanic rises are both part of the global mid-ocean ridge system.

11. Describe the difference in earthquake magnitudes that occur between the three types of plate boundaries, and include why these differences occur.

Divergent plate boundary: The magnitude of energy release along divergent plate boundaries is closely related to the spreading rate. Earthquakes in the rift valley of the slow-spreading Mid-Atlantic Ridge reach a maximum magnitude of about M_W=6.0, whereas those occurring along the axis of the fast-spreading East Pacific Rise seldom exceed M_W=4.5. These earthquakes are shallow, usually less than 10.0 kilometers (6 miles) in depth. Compared to the other types of plate boundaries, earthquakes along divergent plate boundaries are numerous, but relatively small because the sea floor is continually pulling apart, or rifting, here.

Convergent plate boundary: The forces involved in convergent plate boundary collisions are enormous and create infrequent but powerful earthquakes. Convergent plate boundaries are associated with some of the most powerful earthquakes in the world. Currently, the largest earthquake ever recorded was the Chilean earthquake of 1960 that occurred near the Peru-Chile Trench and had a magnitude of M_W=9.5. Earthquakes associated with convergent boundaries vary from shallow depths near the surface down to 6709 kilometers (415 miles deep); these are the deepest earthquakes in the world. These earthquakes are clustered in a band about 20 kilometers (12.5 miles) thick that closely corresponds to the location of the subduction zone.

Transform plate boundary: As one plate slowly moves past another, shallow but frequently strong earthquakes are produced. Magnitude M_W=7.0 have been recorded along some oceanic transform faults, and the San Andreas Fault (a continental transform fault) has experienced earthquakes up to M_W=8.5. These earthquakes are not as strong as those associated with convergent boundaries because the direction and type of plate movement is different.

12. How can plate tectonics be used to help explain the difference between a seamount and a tablemount?

Most oceanic islands form because of the volcanic activity at oceanic spreading centers. As the lithospheric plates move away from the oceanic ridge, ocean depth increases due to thermal contraction in the lithosphere. The islands will become inactive volcanoes within 30 million years because the plate will have moved and the volcanic islands will no longer be centered over the magma plume rising from the mantle that creates an active volcano. Inactive, they will be carried beneath the ocean's surface. Those that have their surfaces flattened by wave erosion will become tablemounts.

13. How is the age distribution pattern of the Emperor Seamount and Hawaiian Island chains explained by the position of the Hawaiian hotspot? What could have caused the curious bend in between the two chains of seamounts/tablemounts?

From the island of Hawaii, the only active volcano in the chain, there extends a northwest trending line of islands and seamounts to about 188 degrees west longitude. At this point, the island chain makes a bend and turns sharply north as the Emperor Seamount Chain. The volcanoes in the island chain increase in age from Hawaii to about 40 million years (at the bend between Hawaiian Islands and the Emperor Seamount) to about 81 million years at the north end of the Emperor Seamount Chain. The evidence indicates that all of the volcanoes that make up the chains formed when a portion of the ocean floor from which they extend passed over a stationary volcanic hotspot that now underlies the island of Hawaii and Loihi.

The bend probably indicates a change in the direction of the movement of the Pacific Plate. During eruptions of the Emperor Seamounts, the plate was moving past the hotspot in a northerly direction. About 40 million years ago, Pacific Plate movement changed to a northwesterly direction, thus creating the bend in between the two island chains.

14. What are the differences between a mid-ocean ridge and a hotspot?

A mid-ocean ridge is a divergent boundary where two plates are splitting apart. As the plates pull away from one another, there is an abundance of volcanic activity. Hotspots are areas of intense volcanic activity as well, but they are not necessarily associated with any particular type of plate boundary. The vast majority of hotspots do not coincide with plate boundaries; those that do not are concentrated along divergent boundaries where lithospheric plates are relatively thin.

15. Using the paleogeographic reconstructions shown in Figure 2.31, determine when the following events first appear in the geologic record:

a. North America lies on the Equator – 480 million years ago

b. The continents come together as Pangea – 240 million years ago
c. The North Atlantic Ocean opens – 120 million years ago
d. India separates from Antarctica – 60 million years ago

Answers to Critical Thinking Exercises

1. If you could travel back in time with three figures (illustrations) from this chapter to help Alfred Wegener convince scientists of his day that continental drift does exist, what would they be and why?

Wegener was unable to describe the process that caused continental movement because there was an incomplete understanding of the structure of Earth in 1912. Figure 2-10, Process of plate tectonics, would provide Wegener with a modern understanding of Earth's structure and the processes that drive plate movement. Two additional figures that provide supporting evidence for Wegener's theory are Figures 2-13 (a) and (b), Earthquakes and Lithospheric Plates. Please note that student answers may vary.

2. List and describe the three types of plate boundaries. Include in your discussion any sea floor features that are related to these plate boundaries, and include a real-world example of each. Construct a map and cross-section showing each of the three boundary types and the corresponding direction of plate movement.

Figure 2-14 (Three types of plate boundaries) illustrates the three types of plate boundaries (convergent, divergent, and transform) and shows the corresponding direction of plate movement. Convergent plate boundaries move away from the plate boundary; the direction of movement is perpendicular to the plate boundary (example: mid-ocean ridge). Plate movement in which the two plates move toward one another characterizes divergent plate boundaries. In the case of an oceanic plate (basalt) and a continental plate (granite), the denser oceanic plate is thrust below the continental plate. The area of plate overlap is called a subduction zone. Transform faults occur in areas where the movement of the two plates is in opposite directions and parallels the plate boundary.

3. Convergent plate boundaries can be divided into three types based on the type of crust contained in the two colliding plates. Compare and contrast the different types of convergent boundaries that result from these collisions.

Oceanic-Continental Plate Convergence: When an oceanic and a continental plate converge, the denser oceanic plate will be subducted, forced below the continental plate. As the plate descends, some of the material is melted and mixes with other melted rock to produce an andesitic continental arc.
Oceanic-Oceanic Plate Convergence: When two oceanic plates converge, the denser oceanic plate will be subducted. As the plate descends, some of the material is melted and mixes with other melted rock to form a basaltic island arc.
Continental-Continental Plate Convergence: When two continental plates converge, neither plate will be subducted. No volcanic arc is created. In contrast to collisions with oceanic plates, a tall, uplifted mountain range forms that is composed of folded and deformed sedimentary rock.

4. **Describe the differences in origin between the Aleutian Islands and the Hawaiian Islands. Provide evidence to support your explanation.**

The Aleutian Islands are created by the subduction of the Pacific Plate into the Aleutian Trench. As the subducted plate melts, the material mixes with other molten rocks and creates an andesitic volcanic island arc. Any volcanoes in the island arc could be active at anytime due to continuing subduction.

The Hawaiian Islands are a nematah created by the Pacific Plate passing over the Hawaiian hotspot. The eruptions associated with the Hawaiian hotspot produce mostly basaltic lava. Only the volcanoes on the island (or two) directly over the hotspot are active, and each island further from the hotspot is progressively older.

5. **Assuming that a continent moves at a rate of 10 centimeters per year, how long would it take to travel from your present location to a nearby large city? Also, calculate how long it would take you to travel across the United States from the East Coast to the West Coast.**

The answer to this question will vary as a function of location. As an example, if the nearest large city is 100 kilometers (60 miles away), then:

100 km X (1000 m/km) X (100 cm/m) X (1 year/10 cm) = 1,000,000 or 10^6 years. One million years is a surprisingly short length of geologic time for moving such a large distance.

The distance between Washington, D.C. (East Coast) and San Francisco, California (West Coast) is 4021 km (2498 miles), so:

4021 km X (1000 m/km) X (100 cm/m) X (1 year/10 cm) = 40,210,000 years or 40.21 X 10^6 years. Forty million years is a surprisingly short length of geologic time for moving such a large distance.