EXERCISE 10

The Dynamic Ocean Floor

One of the most significant scientific revelations of the 20th century was the realization that the ocean basins are young, ephemeral features. Based on this discovery, a revolutionary theory called *plate tectonics* evolved that helps to explain and interrelate earthquakes, mountain building, the origins of ocean basins, and other geologic events and processes. This exercise examines some of the lines of evidence that have been used to verify this comprehensive model of the way Earth scientists view the restless Earth.

Objectives

After you have completed this exercise, you should be able to:

1. List and explain the lines of evidence that support the theory of plate tectonics.
2. Locate and describe the mid-ocean ridge system and deep-ocean trenches.
3. Describe the relation between earthquakes and plate boundaries.
4. Describe the magnetic polarity reversals that have taken place on Earth in the last four million years.
5. Determine the rate of seafloor spreading that occurs along a mid-ocean ridge by using paleomagnetic evidence.
6. Use the rate of seafloor spreading for an ocean basin to determine its age.
7. Describe the three types of plate boundaries and the motion of the plates that occurs along each boundary.

Materials

calculator ruler colored pencils

Materials Supplied by Your Instructor

atlas, globe, or world wall map

Terms

plate tectonics	rift valleys	paleomagnetism
lithosphere	deep-ocean trench	seafloor spreading
plates	Pangaea	
mid-ocean ridge	continental drift	

Introduction

Since the early days of sailing vessels, the investigation of the ocean floor has been both a challenge and a source of new understanding about the mechanisms of the dynamic Earth. Using the information gathered over the years concerning the topography, age, and method of evolution of the ocean basins, Earth scientists have developed an important theory called **plate tectonics**. Plate tectonics is the foundation used by modern geology to help explain the origin of mountains and continents, the occurrence of earthquakes, the evolution of ocean basins, the development and distribution of plants and animals, as well as many other geologic processes.

Plate tectonics postulates that the **lithosphere** of Earth is broken into several large, rigid slabs called **plates**. These plates and the continents on them are moving. Where the plates are separating along the **mid-ocean ridges**, new ocean floor crust is forming. Further, along the axis of some ridge segments are deep down-faulted structures called **rift valleys**. Along the plate margins, earthquakes are generated as plates slide past each other, collide to form mountains, or override each other causing **deep-ocean trenches**.

The idea that our present-day continents at one time were parts of a single supercontinent was stated in 1912 by Alfred Wegener. His hypothesis, called **continental drift**, proposed that long ago a supercontinent called **Pangaea** broke apart into the present continents (Figure 10.1). Over a period of millions of years, each of the continents drifted across Earth's surface to its current position. Among the lines of evidence used to support this hypothesis were (1) the geometric fit of the continents, (2) the fit of geologic structures (mountains, etc.) and rock ages across oceans, (3) the global distribution of fossils (*paleontology*), and (4) ancient climates (*paleoclimatology*).

In the 1960s great advances resulting from new technologies in oceanographic research, such as the ocean research vessel *Glomar Challenger*, brought new evidence in support of many of Wegener's ideas. Research concerning rock magnetism, the cause and distribution of earthquakes, and the age of ocean sediments led to the development of a much broader theory than continental drift. The expanded theory is known as *plate tectonics*.

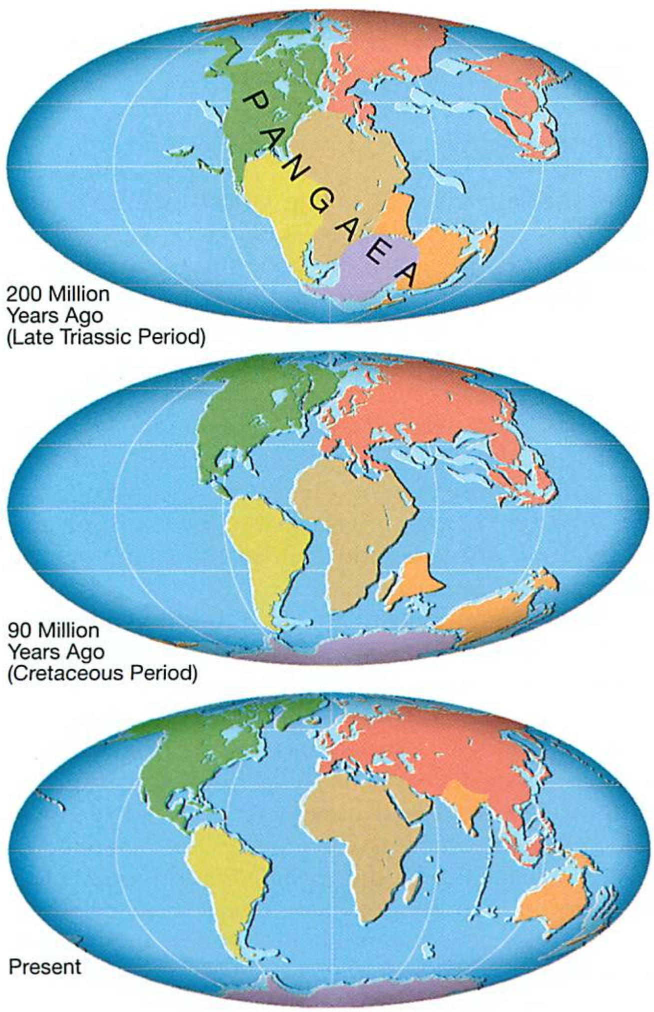

Figure 10.1 Pangaea, as it is thought to have appeared 200 million years ago. (After R. S. Dietz and J. C. Holden, *Journal of Geophysical Research* 75: 4943.)

The Evidence for Plate Tectonics

Prior to the plate tectonics theory, the origin of many ocean floor features was uncertain. However, today Earth scientists have a much better understanding of these features, especially when viewed as parts of a dynamic, evolving lithosphere. Two of these features, mid-ocean ridges and deep-ocean trenches, are of major importance in understanding plate tectonics.

1. In the following spaces, write brief statements that describe each of the following ocean-floor features.

   Mid-ocean ridge: ______________________

   ____

   ____

   Mid-ocean ridge rift valley: ______________

   ____

   ____

   Deep-ocean trench: ____________________

   ____

   ____

2. Using an atlas and/or world wall map as a reference, accurately draw the global mid-ocean ridge system on the world map, Figure 10.2.
3. Use an atlas and/or world wall map to locate and label each of the following deep-ocean trenches on Figure 10.2. Draw a line to represent the trench. To conserve space, write only the letter of each trench on the map.

   a. Puerto Rico
   b. Cayman
   c. Peru-Chile
   d. Aleutian
   e. Kuril
   f. Japan
   g. Mariana
   h. Tonga
   i. Kermadec
   j. Java

Fit of the Continents

Examine the east coast of South America and the west coast of Africa on the world map, Figure 10.2. Then answer questions 4–7.

4. The shape of the east coast of South America conforms to the shape of the (east, west) side of the mid-ocean ridge in the central South Atlantic Ocean. Circle your answer.
5. The shape of the west coast of Africa conforms to the shape of the (east, west) side of the mid-ocean ridge in the South Atlantic Ocean. Circle your answer.
6. If South America and Africa were moved to the mid-ocean ridge, their shapes (would, would not) fit together along the ridge. Circle your answer.

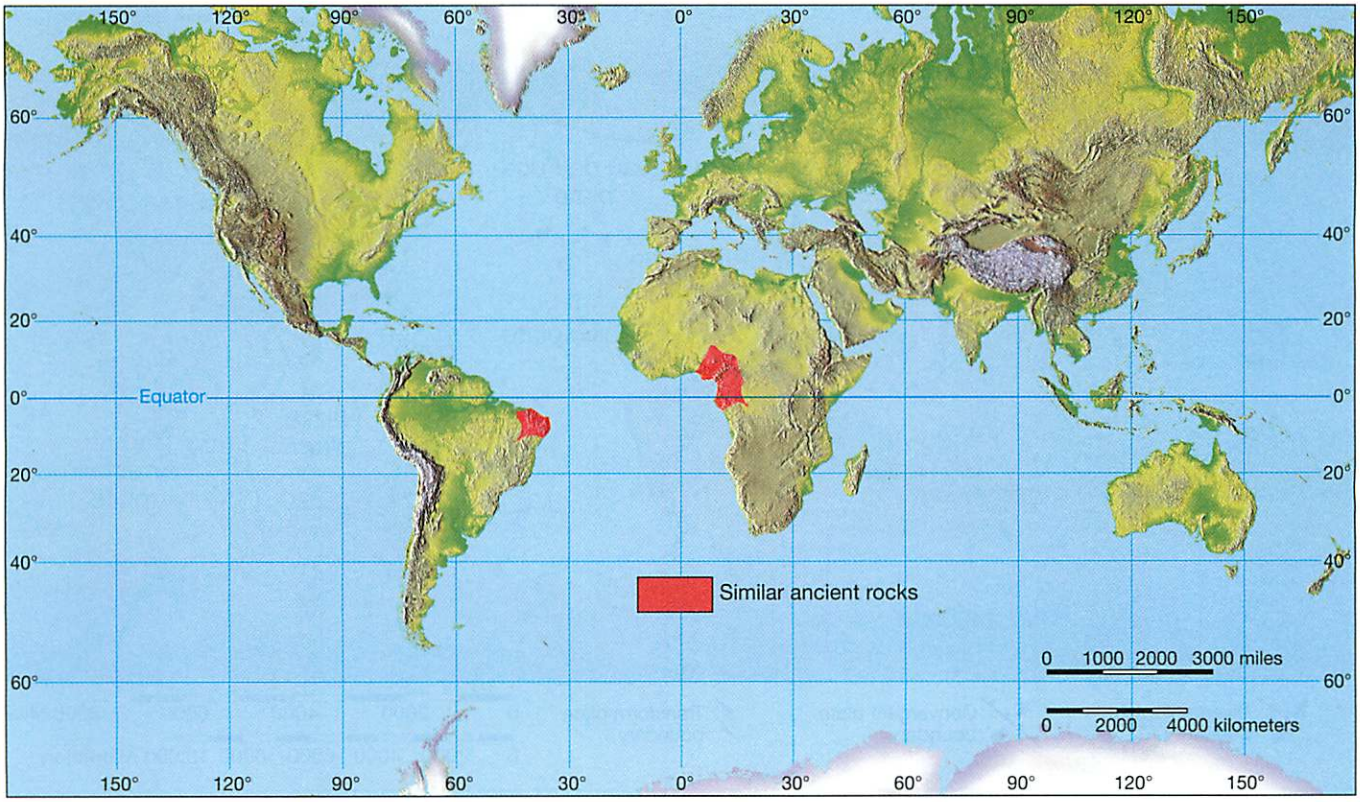

Figure 10.2 World map.

Notice on Figure 10.2 that the ages of the rocks in eastern South America and western Africa are similar. The rocks that comprise the ocean floor separating the two continents are much younger.

7. If the South American and African continents are brought together at the mid-ocean ridge, do the areas of ancient rocks match? Does the match support the idea that these continents were once joined?

___

___

(*Note:* Actually, the fit of the continents is more exact on a globe because flat maps have distortions. Also, using the seaward edge of the continental shelf rather than the coastline would be more accurate.)

8. In Figure 10.1, identify each of the present-day continents that comprised Pangaea by writing their names at the proper locations on the top figure.

Earthquakes

The distribution and depths of earthquakes provide evidence for the mechanics of plate tectonics.

Examine the world map of plates, Figure 10.3, and compare it to the earthquake distribution map, Figure 8.9, in Exercise 8. Use the maps and Figure 10.2 to answer questions 9–11.

9. Most deep-focus earthquakes are associated with (mid-ocean ridges, deep-ocean trenches). Circle your answer.
10. Most mid-ocean, shallow-focus earthquakes are associated with (mid-ocean ridges, deep-ocean trenches).
11. After you compare the earthquake distribution map to the plate map, write a brief statement describing the relation between earthquakes and the rigid plates that comprise Earth's outer shell.

___

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Paleomagnetism

Some minerals in igneous rocks develop a slight magnetism in alignment with Earth's magnetic field at the time of their formation. Also, scientists have discovered that the polarity of Earth's magnetic field has periodically reversed and the North Magnetic Pole becomes the South Magnetic Pole, while the South Magnetic Pole becomes the North Magnetic Pole. Putting these facts together provides additional support for plate tectonics.

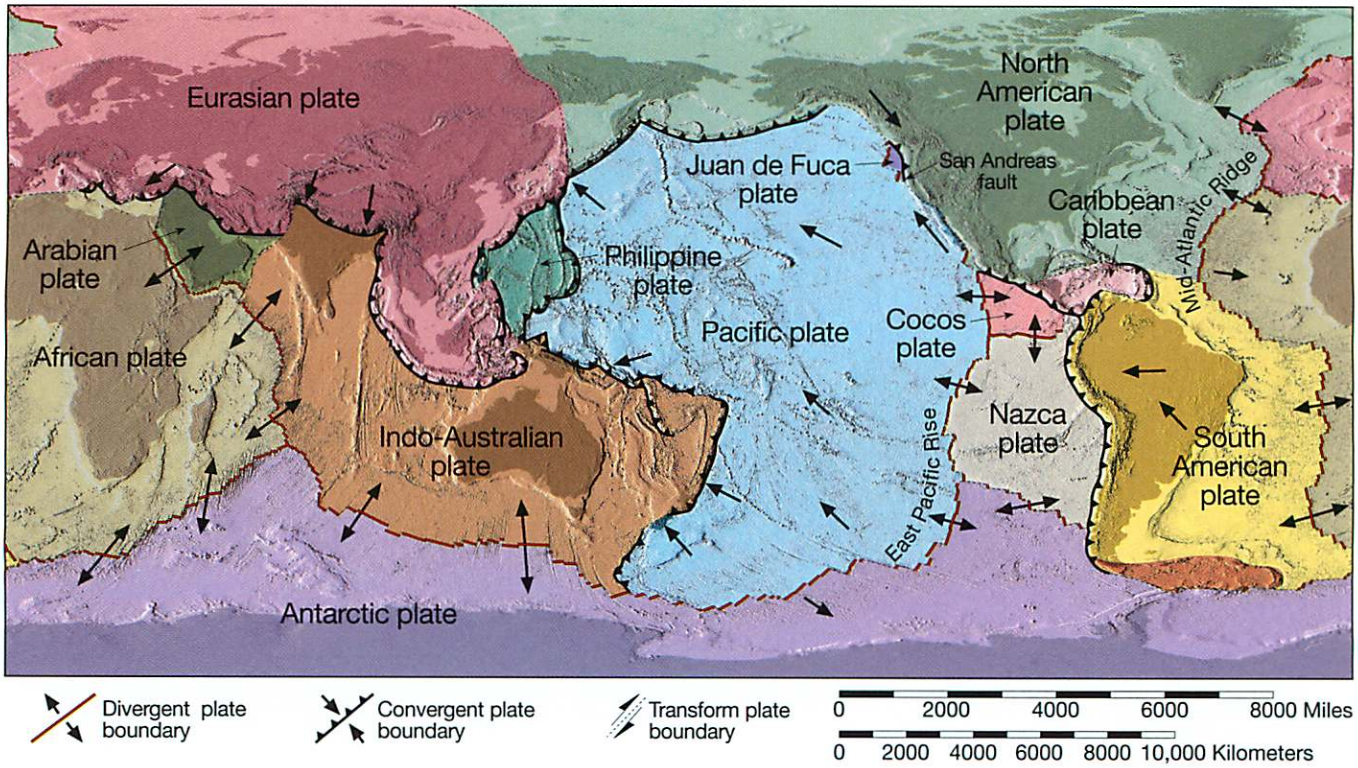

Figure 10.3 The mosaic of rigid plates that constitutes Earth's outer shell. (After W. B. Hamilton, U.S. Geological Survey)

The ancient magnetism, called **paleomagnetism**, present in rocks on the ocean floor can be used to determine the rate at which the plates are separating and, consequently, the time when they began to separate. Where plates separate along the mid-ocean ridge, magma from the mantle rises to the surface and creates new ocean floor. As the magma cools, the minerals assume a magnetism equal to the prevailing magnetic field. As the plates continue to separate and Earth's magnetic field reverses polarity, new material forming at the ridge is magnetized in an opposite (or *reversed*) direction.

Scientists have reconstructed Earth's magnetic polarity reversals over the past several million years. A generalized record of these polarity reversals is shown in graphic form in Figure 10.4. The periods of normal polarity, when a compass needle would have pointed North as it does today, are shown in color and labeled a–f for reference. Use Figure 10.4 to answer questions 12–17.

12. The magnetic field of Earth has had (3, 5, 7) intervals of reversed polarity during the past 4 million years. Circle your answer.

13. Approximately how long ago did the current normal polarity begin?

_______ years ago

14. One and a half million years ago the indicator on a compass needle would have pointed to the (North, South). Circle your answer.

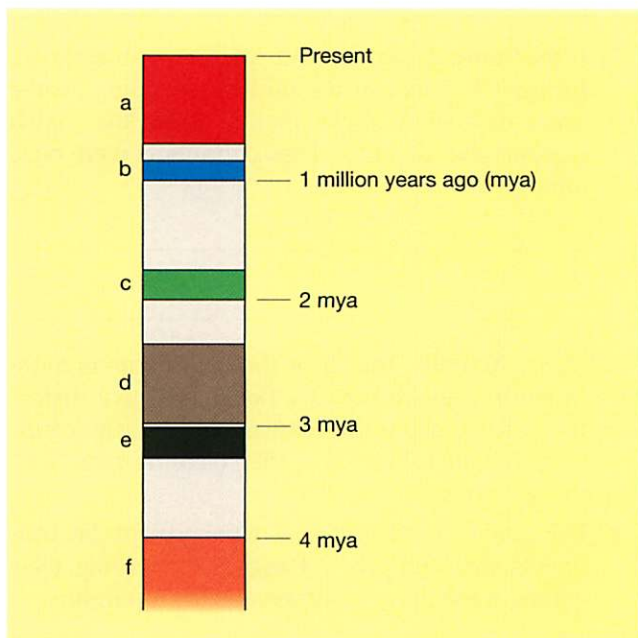

Figure 10.4 Chronology of magnetic polarity reversals on Earth during the last 4 million years. Periods of normal polarity, when a compass would have pointed North as it does today, are shown in color. Periods of reverse polarity are shown in white. (Data from Allan Cox and G. Dalrymple)

15. The period of normal polarity, c, began (1, 2, 3) million years ago.
16. During the past 4 million years, each interval of reverse polarity has lasted (more, less) than 1 million years. Circle your answer.
17. Based upon the pattern of magnetic changes exhibited in Figure 10.4, does it appear as though Earth is due for another magnetic polarity reversal in the near future?

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Paleomagnetism and the Ocean Floor

The records of the magnetic polarity reversals that have been determined from the oceanic crust across sections of the mid-ocean ridges in the Pacific, South Atlantic, and North Atlantic oceans are illustrated in Figure 10.5. As new ocean crust forms along the mid-ocean ridge, it spreads out equally on both sides of the ridge. Therefore, a record of the reversals is repeated (mirrored). Notice that the general pattern of polarity reversals presented in Figure 10.4 can be matched with the polarity of the rocks on either side of the ridge for each ocean basin in Figure 10.5.

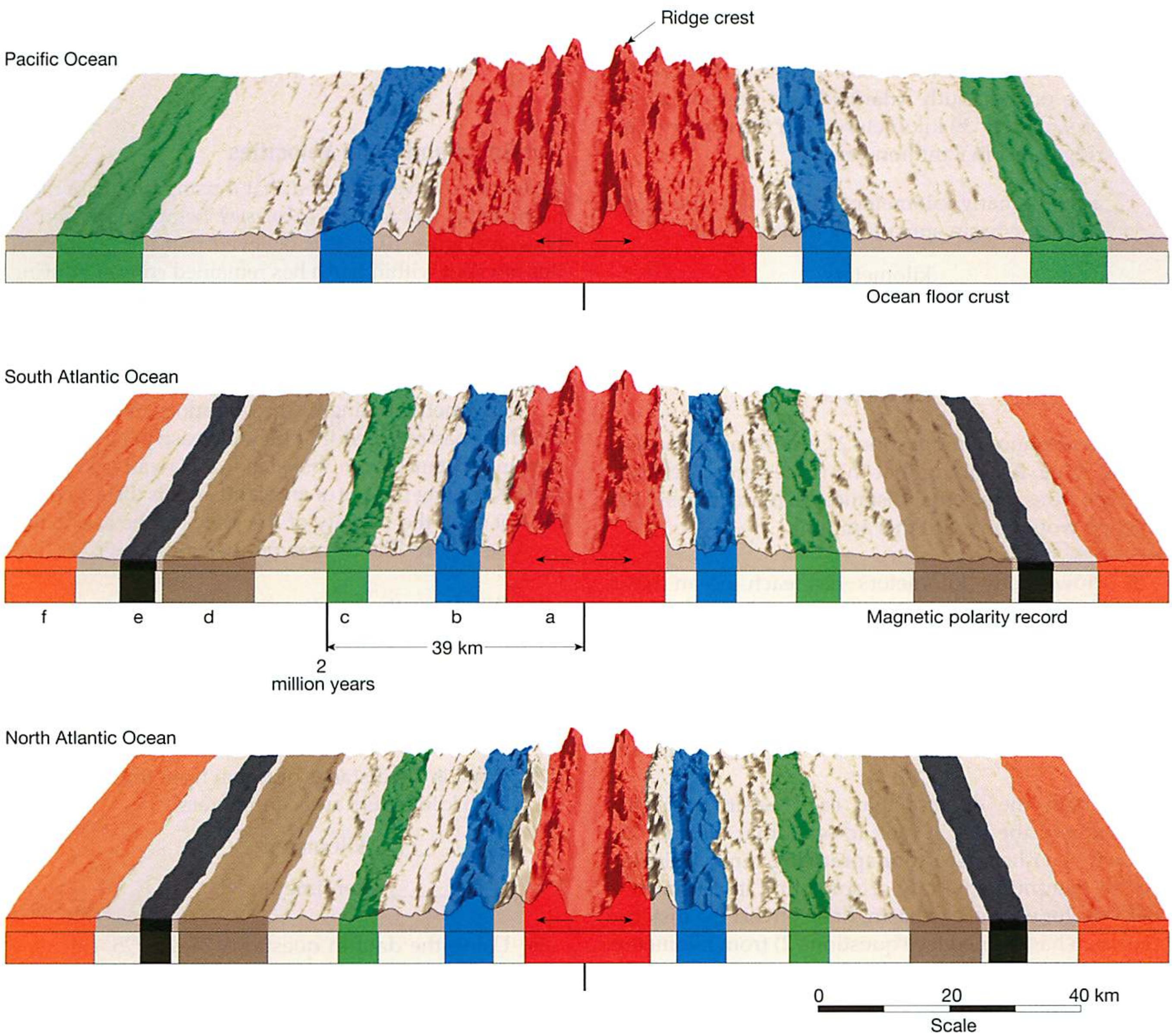

Figure 10.5 Generalized record of the magnetic polarity reversals near the mid-ocean ridge in the Pacific, South Atlantic, and North Atlantic oceans. Periods of normal polarity are shown in color and correspond to those illustrated in Figure 10.4.

Use Figures 10.4 and 10.5 to answer questions 18–23.

18. On Figure 10.5, identify and mark the periods of normal polarity with the letters a–f (as in Figure 10.4) along each ocean floor. Begin at the ridge crest and label along both sides of each ridge. (*Note:* The left side of the South Atlantic has already been done and can act as a guide. Also, only the periods of normal polarity through c are illustrated in the Pacific basin.)

19. Using the South Atlantic as an example, label the beginning of the normal polarity period c, "2 million years ago," on the left sides of the Pacific and North Atlantic diagrams.

20. Using the distance scale in Figure 10.5, the (Pacific, South Atlantic, North Atlantic) has spread the greatest distance during the last 2 million years. Circle your answer.

21. Refer to the distance scale. Notice that the left side of the South Atlantic basin has spread approximately 39 kilometers from the center of the ridge crest in 2 million years.

a. How many kilometers has the left side of the Pacific basin spread in 2 million years?

_____________ kilometers

b. How many kilometers has the left side of the North Atlantic basin spread in 2 million years?

_____________ kilometers

The distances in question 21 are for only one side of the ridge. Assuming that the ridge spreads equally on both sides, the actual distance each ocean basin has opened would be twice this amount.

22. How many kilometers has each ocean basin opened in the past 2 million years?

Pacific Ocean basin: _______ kilometers

South Atlantic Ocean basin: _______ kilometers

North Atlantic Ocean basin: _______ kilometers

If both the *distance* that each ocean basin has opened and the *time* it took to open that distance are known, the rate of **seafloor spreading** can be calculated. To determine the rate of spreading in centimeters per year for each ocean basin, first convert the distance the basin has opened (see question 22) from kilometers to centimeters and then divide this distance by the time, 2 million years.

23. Determine the *rate of seafloor spreading* for the Pacific and North Atlantic Ocean basins. As an example, the South Atlantic has already been done.

a. South Atlantic: distance =

$78 \text{ km} \times 100{,}000 \text{ cm/km} = 7{,}800{,}000 \text{ cm}$

$\text{Rate of spreading} = \dfrac{7{,}800{,}000 \text{ cm}}{2{,}000{,}000 \text{ yr}} = 3.9 \text{ cm/yr}$

b. Pacific: distance = ____ km × 100,000 cm/km

= _____________ cm

Rate of spreading = $\dfrac{\_\_\_\_\_\_\_\_\_\_\_\_ \text{ cm}}{\_\_\_\_\_\_\_\_\_\_\_\_ \text{ yr}}$

= _____________ cm/yr

c. North Atlantic: distance = _________ km

× 100,000 cm/km = _____________ cm

Rate of spreading = $\dfrac{\_\_\_\_\_\_\_\_\_\_\_\_ \text{ cm}}{\_\_\_\_\_\_\_\_\_\_\_\_ \text{ yr}}$

= _____________ cm/yr

Hot Spots and Plate Velocities

Researchers have proposed that a rising plume of mantle material has formed a *hot spot* below the island of Hawaii (Figure 10.6). It is believed that the position of this hot spot within Earth has remained constant during a very long period of time. In the past, as the Pacific plate has moved over the hot spot, the successive volcanic islands of the Hawaiian chain have been built. Today the island of Hawaii is forming over this mantle plume.

Radiometric dating of the volcanoes in the Hawaiian chain has revealed that they increase in age with increasing distance from the island of Hawaii (see Figure 10.6). Knowing the age of an island and its distance from the hot spot, the velocity of the plate can be calculated.

Use Figure 10.6 to answer questions 24–26.

24. What are the minimum and maximum ages of the island of Kauai?

Minimum age: ______ million years

Maximum age: ______ million years

25. What is the distance of Kauai from the hot spot in both kilometers and centimeters?

_____________ kilometers

_____________ centimeters

26. Using the data in questions 24 and 25, calculate the approximate maximum and minimum velocities, in centimeters per year (cm/yr), of the Pacific plate as it moved over the Hawaiian hot spot.

Maximum velocity: __________ cm/yr

Minimum velocity: __________ cm/yr

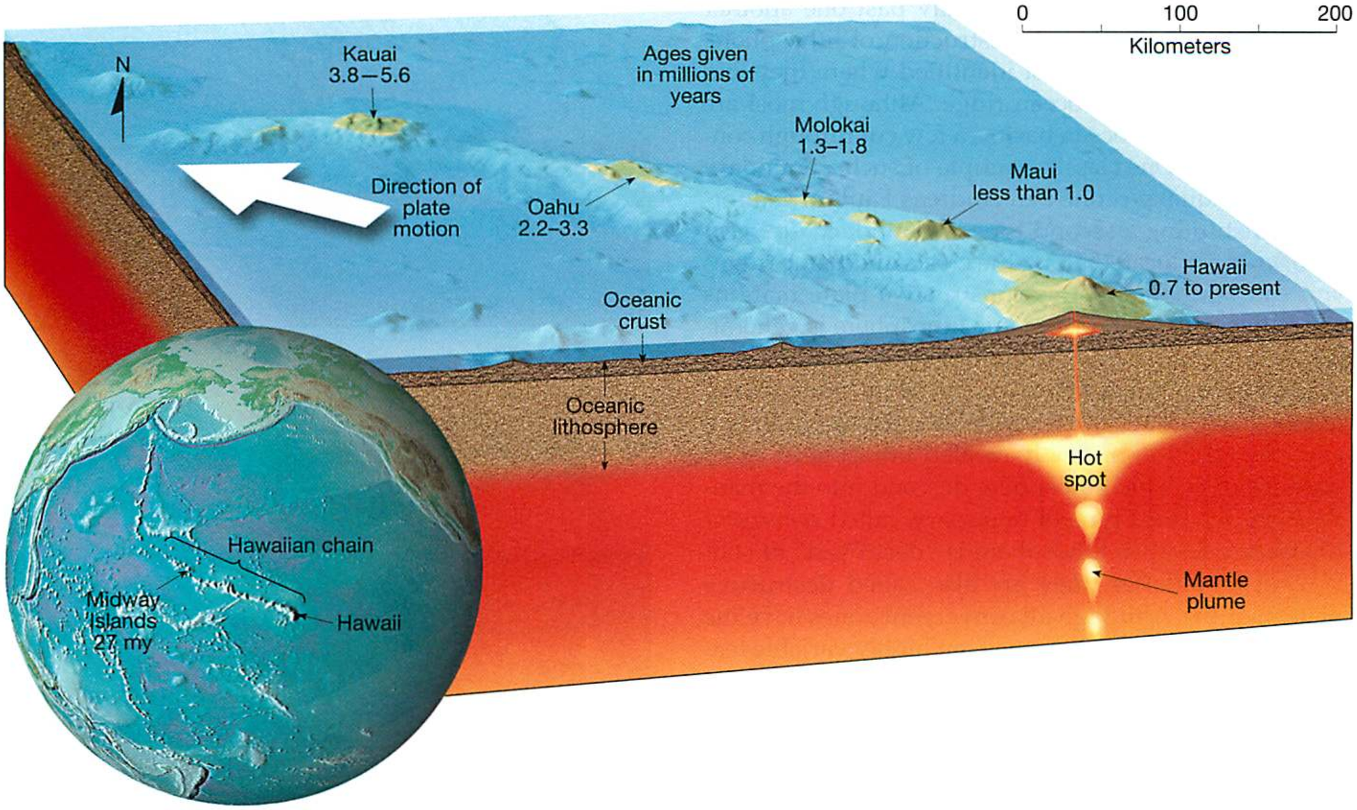

Figure 10.6 Movement of the Pacific plate over a stationary hot spot and the corresponding radiometric ages of the Hawaiian Islands in millions of years.

Ocean Basin Ages

To estimate how many millions of years ago the North Atlantic and South Atlantic Ocean basins began forming, complete questions 27–29.

27. On a large wall map or globe, accurately measure the distance between the seaward edges of the continental shelves from eastern North America at North Carolina to northwestern Africa at Mauritania (20°N latitude). Determine the distance in kilometers, then convert to centimeters. (*Note:* If you have completed Exercise 22, "Location and Distance on Earth," you may find it easier to determine the great circle distance between the two.)

    Distance = ____________________ kilometers

    = ____________________ centimeters

28. Divide the distance in centimeters separating the continents that you measured in question 27 by the rate of seafloor spreading for the North Atlantic basin, calculated in question 23c. Your answer is the approximate age in years of the North Atlantic Ocean basin.

    Distance/Rate of seafloor spreading =

    ____________________ =

    Age of the North Atlantic Basin: ________ years

Use the same procedure you used in question 28 to determine the age of the South Atlantic basin. Measure the distance between the continents along an east–west line from the eastern edge of Brazil directly east to Africa. (*Note:* You may want to determine the total number of degrees of longitude separating the two and then use the Table 22.1, "Longitude as Distance," in Exercise 22, to calculate the distance.) Use the rate of seafloor spreading for the South Atlantic in your calculation.

29. How many years ago did South America and Africa begin to separate?

    Age of the South Atlantic Basin: ________ years

30. Write your calculated ages of the North and South Atlantic Ocean basins on the map in Figure 10.2. Also on Figure 10.2, use the world map of plates in Figure 10.3 as a reference and draw arrows on all the major plates showing their directions of movement.

Plate Boundaries

Earth scientists recognize three distinct types of plate boundaries, with each distinguished by the movement of the plates associated with it. Along *transform fault* *boundaries*, plates slide horizontally past one another without the production or destruction of lithosphere. Transform faults were first identified where they join offset segments of an ocean ridge. Although most are located within the ocean basins, a few cut through continental crust. One classic example of such a boundary is the earthquake-prone San Andreas Fault of California. Constituting a second type of boundary, *divergent boundaries* are located along the crests of oceanic ridges and can be thought of as constructive plate margins since this is where new oceanic lithosphere is generated. Although new lithosphere is constantly being produced at the oceanic ridges, our planet is not growing larger—its total surface area remains the same. To balance the addition of newly created lithosphere, older portions of oceanic lithosphere descend into the mantle along the third type of boundary, called *convergent boundaries*. Because lithosphere is "destroyed" at convergent boundaries, they are also called destructive plate margins. Although all convergent zones have the same basic characteristics, they are highly variable features. Each is controlled by the type of crustal material involved and the tectonic setting. Convergent boundaries can form between two oceanic plates, one oceanic plate and one continental plate, or two continental plates (Figure 10.3).

The three diagrams in Figure 10.7 illustrate each type of plate boundary. Use the figure to answer questions 31–33.

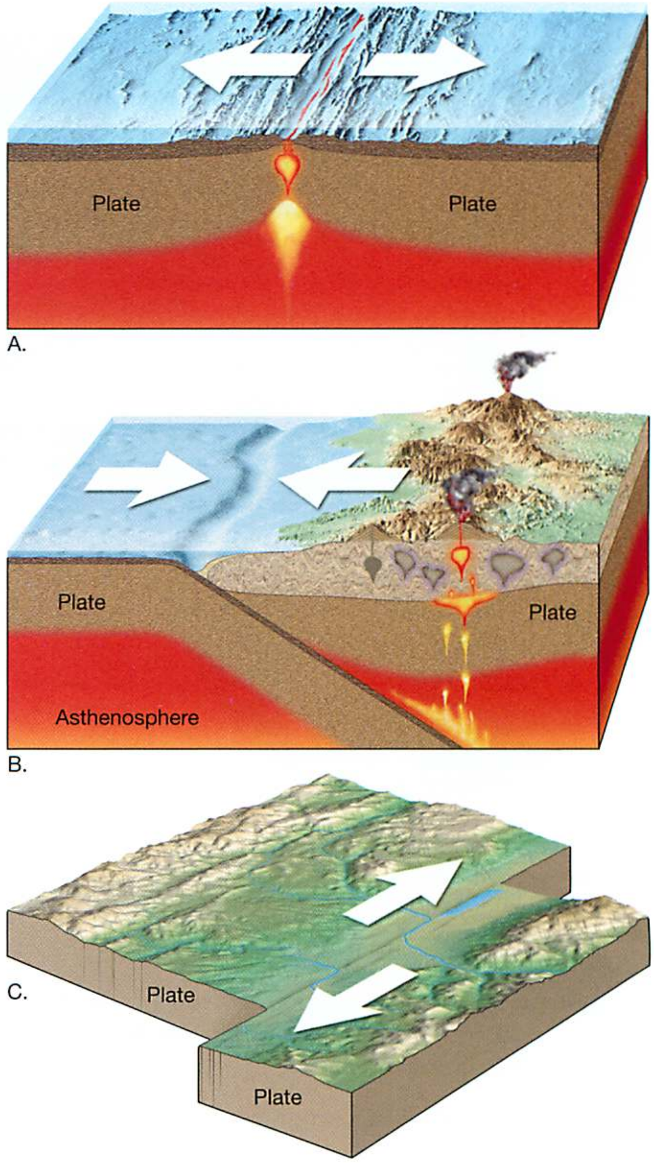

Figure 10.7 Schematic illustrations of the three types of plate boundaries.

31. Figure 10.7A represents a (convergent, divergent, transform) plate boundary. Circle your answer.

a. The plates along the boundary are (spreading, colliding). Circle your answer.

b. This type of plate boundary occurs at (deep-ocean trenches, mid-ocean ridges). Circle your answer.

c. This type of plate boundary results in (construction, destruction) of lithospheric material. Circle your answer.

32. Figure 10.7B represents a (convergent, divergent, transform) plate boundary. Circle your answer.

a. The plates along this type of boundary are (spreading, colliding). Circle your answer.

b. Briefly describe each of the following types of plate convergence. Using Figure 10.3 as a general reference, give a specific example of a physical feature on Earth that has formed as a result of each type.

Oceanic–continental convergence: ____________

____

Feature: ______________________________

Oceanic–oceanic convergence: ______________

____

Feature: ______________________________

Continental–continental convergence: ________

____

Feature: ______________________________

33. Figure 10.7C represents a (convergent, divergent, transform) plate boundary. Circle your answer.

a. Lithospheric material (is being created, is being destroyed, remains unchanged) along this type of boundary. Circle your answer.

b. What type of faults are likely to parallel the direction of plate movement along this type of boundary? Write a brief description of the fault.

_______________ faults; _______________

____

Igneous Rocks and Plate Boundaries

The theory of plate tectonics provides a framework for explaining the occurrence of many igneous rocks and the features they compose. The formation of magma is most frequently associated with weaknesses along the boundaries between lithospheric plates.

Figure 10.8 illustrates a few generalized geologic events that are happening along some plate boundaries. Examine the figure closely. Then, use Figure 10.8 to complete questions 34–39.

34. On Figure 10.8, indicate the direction of movement of the plates on both sides of the mid-ocean ridge by drawing arrows on the ocean floor.

35. The ocean floor is composed of the igneous rock (granite, basalt). Circle your answer.

36. The eruption of basaltic magma from the part of the mantle called the *asthenosphere* is associated with what ocean features?

_______________ and _______________

37. Volcanic islands in the ocean, such as the Hawaiian Islands, form over (trenches, hot spots) in the athenosphere and are made of the igneous rock (granite, basalt). Circle your answers.

38. (Deep-ocean trenches, Mid-ocean ridges) form on the ocean floor where oceanic plates are descending beneath continents.

39. As oceanic plates descend beneath the continents, the plates (remain solid, partially melt) and produce pockets of magma in the continents. These magma chambers are the sources of lava that form (ridges, volcanoes) on the continents. Circle your answers.

The Ocean Floor on the Internet

Continue your exploration of the topics presented in this exercise by applying the concepts you have learned to the corresponding online activity on the *Applications & Investigations in Earth Science* website at http://prenhall.com/earthsciencelab

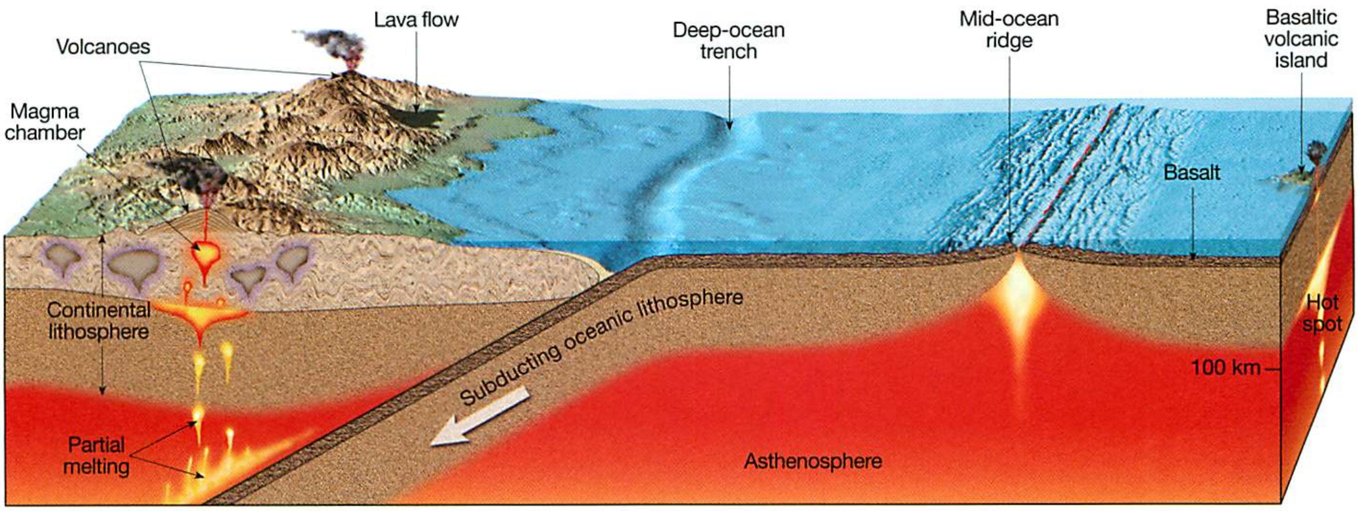

Figure 10.8 Ocean-floor features and the occurrence of magma along plate boundaries.

Notes and calculations.

The Dynamic Ocean Floor

Date Due: ______________________

Name: ______________________

Date: ______________________

Class: ______________________

After you have finished Exercise 10, complete the following questions. You may have to refer to the exercise for assistance or to locate specific answers. Be prepared to submit this summary/report to your instructor at the designated time.

1. In the following space, draw a general profile of an ocean floor between two continents illustrating a mid-ocean ridge and a deep-ocean trench. Label each of the features and draw arrows showing plate motion.

Ocean Floor Profile

2. Deep-focus earthquakes are associated with what ocean-floor features?

____

3. Shallow-focus earthquakes are associated with what ocean-floor features?

____

4. Earthquake foci can be used to mark the boundaries of what Earth features?

____

5. Describe how paleomagnetism is used to calculate the rate of seafloor spreading.

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____

6. From question 23 in the exercise what were your calculated rates of seafloor spreading for the following ocean basins?

   Pacific Ocean basin: ________ cm/yr

   North Atlantic Ocean basin: ________ cm/yr

7. From question 26 in the exercise, what was your calculated maximum velocity for the Pacific plate near the Hawaiian Islands?

____

8. From questions 28 and 29 in the exercise, what were your calculated ages for the North and South Atlantic Ocean basins?

   North Atlantic: ________ million years old

   South Atlantic: ________ million years old

9. In the following space, draw a profile of a typical divergent plate boundary. Show the motion of the plates with arrows. Explain what will happen along the boundary between the plates.

Profile of a Divergent Plate Boundary

Explanation: ______________________

____

____

10. Describe the origin of volcanoes on the ocean floor and along continental margins bordering ocean trenches.

Ocean-floor volcanoes: ______________________

____

____

Volcanoes along continental margins bordering ocean trenches:

____

____

____

11. Figure 10.9 illustrates a generalized cross-section of the plate boundary along the western edge of South America. Use Figure 10.9 to answer the following questions.

a. Label each of the following features on Figure 10.9.

asthenosphere	continental crust
deep-ocean trench	oceanic crust
continental volcanic arc	continental lithosphere
	oceanic lithosphere

b. What type of plate boundary is illustrated by the figure? Write a general description of this type of boundary.

____

____

____

____

c. Referring to Figure 10.3, identify by name the plates illustrated in the block diagram in Figure 10.9. Write the name of each plate at the appropriate location on the block diagram.

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12. In your own words, describe the theory of plate tectonics. List at least two lines of evidence used to support the theory.

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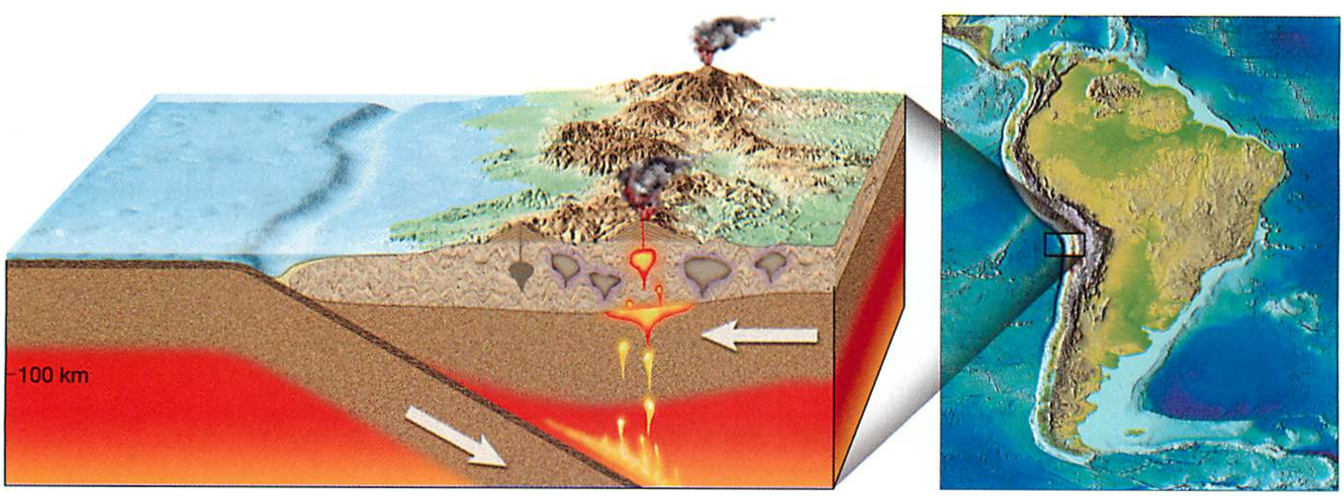

Figure 10.9 Generalized cross-section of the plate boundary along the western edge of South America.