

9.2 Sea-Floor Spreading



1 FOCUS

Section Objectives

- 9.4 Identify** mid-ocean ridges and deep-ocean trenches.
- 9.5 Explain** the processes of sea-floor spreading and subduction.
- 9.6 Explain** the evidence for sea-floor spreading, including paleomagnetism and magnetic reversals, earthquake patterns, and the age of the ocean floor.

Reading Focus

Build Vocabulary

L2

Word Parts Have students break the word subduction into roots, prefixes, or suffixes. They may need to use a dictionary to find the meaning of some parts. (Subduction comes from the Latin prefix sub-, meaning “below” and the Latin root word ducere, meaning “to draw or pull.” Thus, subduction means to draw or pull below.)

Reading Strategy

L2

- magnetic stripes in ocean-floor rock
- earthquake patterns in subduction zones
- age of the ocean floor

2 INSTRUCT

Exploring the Ocean Floor

L2

Integrate Biology Tell students that the organisms in Figure 7, called tubeworms, live in an ecosystem that does not depend on the sun for its energy. Instead, energy for the ecosystem comes from the hot water escaping from the hydrothermal vent in the photo. The hot water dissolves minerals in ocean-floor rock and provides energy for chemical reactions that produce compounds used by the organisms. Ask: **What is the energy source that heats the water in a hydrothermal vent?** (The water is heated by magma or hot rock beneath the ocean floor, which is made of volcanic rock.)

Verbal, Logical

Reading Focus

Key Concepts

- What are mid-ocean ridges and deep-ocean trenches?
- What occurs during sea-floor spreading?
- What is the evidence for sea-floor spreading?

Vocabulary

- ◆ sonar
- ◆ deep-ocean trench
- ◆ mid-ocean ridge
- ◆ rift valley
- ◆ sea-floor spreading
- ◆ subduction
- ◆ paleomagnetism

Reading Strategy

Identifying Supporting Evidence Copy the graphic organizer. After you read, complete it to show the evidence that supported the hypothesis of sea-floor spreading.

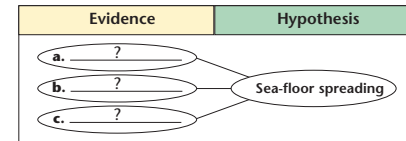
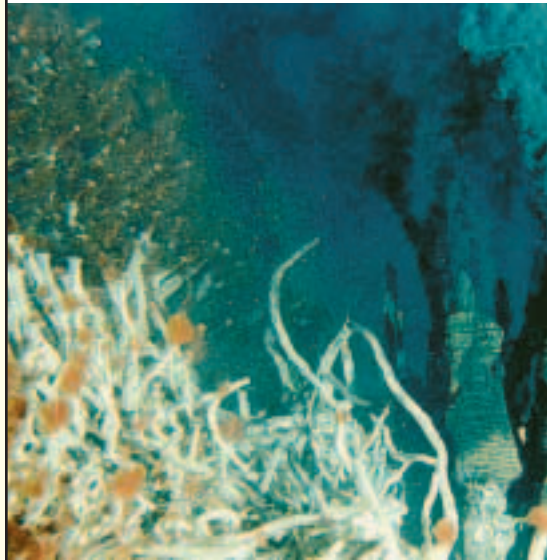


Figure 7 This hot-water vent on the ocean floor is evidence of volcanic activity along the mountain range that winds through Earth’s oceans. Dissolved minerals cloud the water streaming from this vent.



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Wegener published his book *On the Origin of Continents and Oceans* in 1915. During the decades that followed, very few scientists studied continental drift. But discoveries in other branches of Earth science eventually led to new interest in Wegener’s hypothesis. Surprisingly, important new data came from one of the least-known parts of Earth—the ocean floor.

Exploring the Ocean Floor

During the mid-1800s, several nations sent ships on scientific expeditions to gather data about the oceans. Scientists wanted to know more about the topography of the ocean floor. They measured ocean depths in many areas. Data from the middle of the Atlantic Ocean, where scientists expected the water to be very deep, revealed large undersea mountains. This discovery helped to fuel interest in mapping the ocean floor.

During the early 1900s, a new technology made it easier to map the ocean floor. **Sonar**, which stands for **sound navigation and ranging**, is a system that uses sound waves to calculate the distance to an object. The sonar equipment on a ship sends out pulses of sound that bounce off the ocean floor. The equipment then measures how quickly the sound waves return to the ship. The deeper the water, the longer it takes the sound waves to return to the ship.

Facts and Figures

World War II and Plate Tectonics Much of the evidence for plate tectonics comes from the structure of the ocean sea floor, and its discovery is largely due to submarines. A submarine can avoid hitting the ocean floor by using sonar. However, sonar signals can be detected by other vessels, so using sonar would give away a submarine’s location. As a result, the U.S. sponsored a large research effort to map the bathymetry, gravity, and

magnetism of the oceans so that submarines could know the depth to the sea floor at a given location without using sonar. The discoveries about the sea floor amazed the Navy researchers. In fact, one U.S. Navy submarine captain, Harry Hess, went on to become a geophysics professor at Princeton University, and was one of the founding discoverers of plate tectonics.

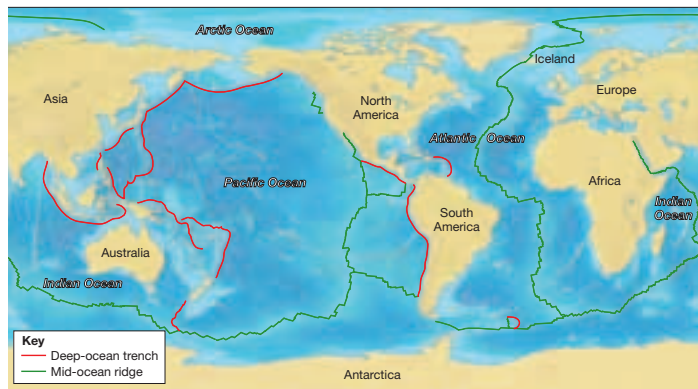


Figure 8 Deep trenches and mountainous mid-ocean ridges are major features of Earth's ocean basins.
Observing Which ocean has the most trenches?

Deep-Ocean Trenches As scientists mapped the ocean floor, they found long, curved valleys along the edges of some ocean basins called deep-ocean **trenches**. Trenches form the deepest parts of Earth's oceans. For example, the Marianas Trench in the Pacific Ocean is over 11 kilometers deep. Most trenches occur around the edges of the Pacific Ocean, although others occur in the Indian and Atlantic oceans.

Mid-Ocean Ridges By the late 1950s, scientists had constructed a more complete map of Earth's ocean floor. The map showed that the mountain range in the middle of the Atlantic Ocean was not an isolated feature. Instead, it formed a **mid-ocean ridge**, a long chain of mountains extending the length of the ocean. 🌐 **Earth's mid-ocean ridge system forms the longest feature on Earth's surface. The system winds more than 70,000 kilometers through all the major ocean basins like the seam on a baseball.** The term *ridge* may be misleading. These features are not narrow like a typical ridge. They range from 1,000 to 4,000 kilometers wide. In a few places, such as Iceland, the mid-ocean ridge rises above the surface.

Often, a deep, central valley runs down the center of a ridge. Called a **rift valley**, the central valley of a mid-ocean ridge resembles a long canyon. Some parts of the ridge system lack a rift valley.



What are mid-ocean ridges?

Composition of the Ocean Floor Earth's ocean floors are made of igneous rocks of basaltic composition. Recall that basalt forms when lava reaches the surface and hardens to form solid rock. Most of the ocean floor is covered with a thick layer of sediment. Scientists found that the sediment layer became thinner closer to mid-ocean ridges, and that along the ridge there was no sediment.



For: Links on mid-ocean ridges
Visit: PHSchool.com
Web Code: cfd-3092

Use Visuals

L1

Figure 8 Have students study the map in Figure 8 showing Earth's ocean floor. Ask: **Where are most trenches found?** (*Around the edges of ocean basins*) **Where are most mid-ocean ridges found?** (*Toward the centers of ocean basins*) When students have read The Process of Sea-Floor Spreading on pp. 256–257, have them revisit Figure 8 and discuss the distribution of mid-ocean ridges and trenches in relation to what they have learned about sea-floor spreading.

Visual, Verbal

Build Science Skills

L2

Ocean Cross Section Using a world atlas or the Internet, find data on ocean depths along a line drawn across the Atlantic Ocean. Use these data to construct a graph that shows how depth changes across the ocean floor. Ask students to label features of the ocean floor, such as the mid-ocean ridge, that appear on the cross section.

Logical, Visual



Find links to additional activities and have students monitor phenomena that affects Earth and its residents.

Facts and Figures

Until the nineteenth century, the ocean floors were considered to be flat, featureless plains. Early attempts to map the ocean floors used soundings taken with weighted lines from ships. This method was slow and inaccurate. In 1855, U.S. Navy Lieutenant Matthew Maury published a bathymetric chart, that showed an underwater mountain range in the middle of the Atlantic Ocean.

In the twentieth century, the use of sonar greatly accelerated sea-floor mapping. Based

on these data, Bruce Heezen and Marie Tharp of Columbia University's Lamont Doherty Earth Observatory began compiling detailed maps of the ocean floor in the 1950s and 1960s. The work of Heezen and Tharp revealed the extent and structure of mid-ocean ridges and trenches and provided evidence in support of sea-floor spreading and plate tectonics. Their 1978 map, World Ocean Floor, was the first complete map of Earth's ocean floor.

Answer to . . .

Figure 8 *the Pacific Ocean*

long chains of mountains that wind across the floors of the oceans

Section 9.2 (continued)

The Process of Sea-Floor Spreading Integrate Oceanography L2

Exploring Ridges and Trenches

Explain that oceanographers have used small submarines called submersibles to explore features of the ocean floor. Have groups of students use library or Internet resources to research the use of submersibles to explore the geology and biology of mid-ocean ridges and deep-ocean trenches. Have each group prepare a poster on their findings and present them to the class.

Verbal, Visual

Build Math Skills L1

Conversion Factors Remind students to label the units of each factor when solving the following problem. Doing this ensures that all the conversion factors are included and the answer has the correct units. Tell students that sea-floor spreading occurs at an average rate of 5 cm per year. At this rate, how long would it take for a narrow sea that is 1 km wide to form? (*about 20,000 years*)

Logical

Figure 9 A spreading center in the Red Sea is slowly causing the sea to become wider.



The Process of Sea-Floor Spreading

The new map of the ocean floor aroused the curiosity of many scientists. One geologist, Harry Hess, thought that the mid-ocean ridges and deep-ocean trenches might help to explain how the ocean floor was formed. In 1963, Hess published his hypothesis of sea-floor spreading. 🌍 **In the process of sea-floor spreading, new ocean floor forms along Earth's mid-ocean ridges, slowly moves outward across ocean basins, and finally sinks back into the mantle beneath deep-ocean trenches.** During sea-floor spreading, new oceanic lithosphere is formed, and the ocean floor gets wider. Today, the Atlantic Ocean is thousands of kilometers wide. Millions of years ago, the Atlantic would have been a narrow sea, like the Red Sea, shown in Figure 9.

Eruptions Along Mid-Ocean Ridges How did the mid-ocean ridges form? Scientists found evidence that the mid-ocean ridges formed as the result of volcanic activity. As shown in Figure 10, fractures along the central valley of a mid-ocean ridge fill with magma that wells up from the hot mantle below. (Recall that magma is molten rock that forms in the upper mantle and rises through the crust). Gradually, the magma cools to produce new slivers of ocean floor. Spreading and upwelling of magma continuously adds new ocean floor.

The process can also begin on land when a rift valley forms and splits a continental landmass. Over millions of years, the rift valley widens to form a new ocean basin like the Red Sea, shown in Figure 9.

Movement of the Ocean Floor As new ocean floor is added along mid-ocean ridges, the older ocean floor moves outward and away from the ridge on both sides. Rates of sea-floor spreading average about 5 centimeters per year. These rates are slow on a human time scale. But they are fast enough that all of Earth's ocean basins could have been formed within the last 200 million years.

Customize for Inclusion Students

Gifted Have students research the contribution of Harry Hess and other scientists to the scientific revolution that led to the modern theory of plate tectonics. Ask them to summarize their findings

in a short essay that explains how understanding of the ocean floor changed as a result of this scientific revolution.

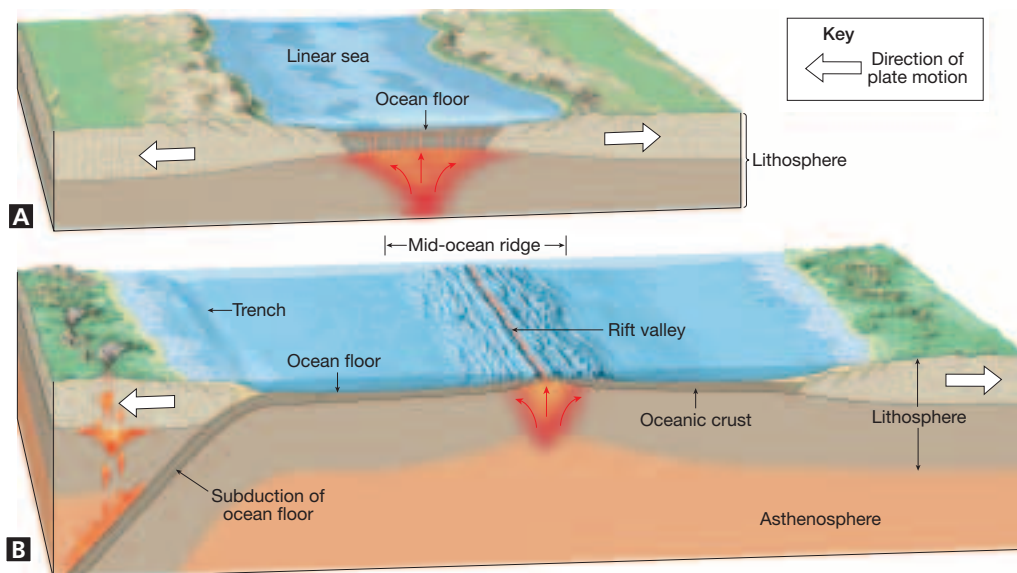


Figure 10 The process of sea-floor spreading produces the ocean floor. **A** A linear sea forms along a spreading center. **B** Over millions of years a mid-ocean ridge develops, the ocean basin becomes wider, and ocean floor is subducted beneath deep-ocean trenches.

Relating Cause and Effect What process adds new material to the ocean floor?

Subduction at Deep-Ocean Trenches Although new ocean floor is constantly being added at the mid-ocean ridges, our planet is not growing larger. Earth's total surface area remains the same. How can that be? To accommodate newly created lithosphere, older portions of the ocean floor return to the mantle. In the process of **subduction**, ocean floor returns to the mantle as it sinks beneath a deep ocean trench. The areas where subduction occurs, shown in Figure 10, are called subduction zones.



What happens during subduction?

Evidence for Sea-Floor Spreading

Hess's hypothesis got the attention of geologists. Sea-floor spreading explained the formation and destruction of ocean floor and how ocean basins could grow wider or close up. But what evidence was there to support Hess's hypothesis? **Evidence for sea-floor spreading included magnetic stripes in ocean-floor rock, earthquake patterns, and measurements of the ages of ocean floor rocks.**

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Facts and Figures

Lakes and Oceans The term *bathymetry* refers to measurements of depth in the oceans. The bathymetry of oceans is the opposite of what you might expect. If you look at a lake, the shallowest parts are usually around the edges, and the deepest parts are usually in the middle. Oceans are just the opposite. Deep-ocean trenches, like the Marianas Trench, Puerto Rico Trench, and

Peru-Chile Trench, are at the edges of the oceans, often adjacent to continents. In the middle of oceans are often found the elevated mountain ranges of mid-ocean ridges like the Mid-Atlantic Ridge. This backward nature of sea-floor bathymetry was an early clue to geoscientists that the oceans were not just large lakes.

Use Visuals

L1

Figure 10 Point out the rising magma in each of the diagrams. Ask: **What happens to the rising magma in the diagram?** (It fills the cracks formed by sea-floor spreading.) **Why is this process called sea-floor spreading?** Does the sea-floor actually get thinner and spread out? (The sea-floor does not get thinner. Rather, the sea-floor spreads apart and new rock is constantly added to the ridge.)

Visual

Build Science Skills

L1

Using Models Give students two colors of modeling clay (one color for the magma and the other color for the crust) and have them model sea-floor spreading, from a mid-ocean ridge to subduction beneath a trench.

Kinesthetic, Visual



Answers to . . .

Figure 10 Eruptions of magma along the mid-ocean ridge



Older parts of the ocean floor sink into the mantle at trenches.

Evidence for Sea-Floor Spreading

Teacher Demo

Testing Minerals for Magnetism

L1

Purpose Students test various minerals with a magnet to determine whether they have magnetic properties.

Materials magnet, minerals (include at least one sample of a mineral that contains iron or cobalt), compass

Procedure Have students test the mineral samples with the magnet to see if they are attracted by it. Have students place the compass near each mineral sample to see if the needle moves. If it does, the material is magnetic.

Expected Outcomes Minerals that contain iron or cobalt, such as lodestone, have magnetic properties. Meteorites also have magnetic properties.

Kinesthetic, Visual

Use Visuals

L1

Figure 12 Have students study the figure. Ask: **Could the rocks in a strip possessing reverse polarity ever possess normal polarity?** (No, once the rocks solidify, their polarity is permanently set.) **How do you think the width of a strip relates to the sea-floor spreading rate?** (The faster the spreading rate is, the wider the strip will be.)

Visual, Logical

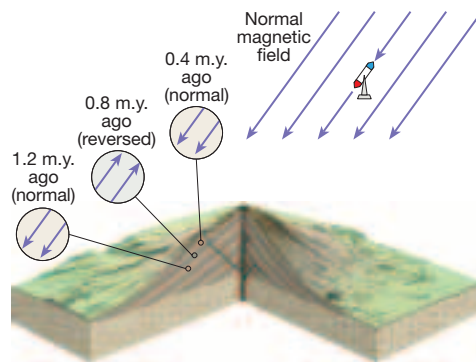
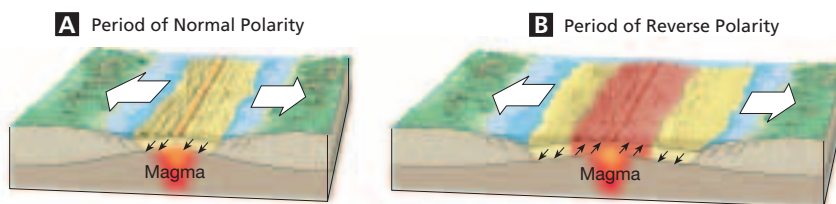


Figure 11 Paleomagnetism in Lava As lava cools, it becomes magnetized parallel to the magnetic field present at that time. When the polarity reverses, a record of the magnetism is preserved in the sequence of lava flows.

Figure 12 A As new material is added to the ocean floor at the oceanic ridges, it is magnetized according to Earth's existing magnetic field. **B** This process records each reversal of Earth's magnetic field. **C** New rock is added in strips of equal size and polarity on both sides of the ridge.

Applying Concepts Why are the magnetized strips about equal width on either side of the ridge?



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Magnetic Strips The magnetic properties of the rock that makes up the ocean floor provided evidence for sea-floor spreading. To understand this evidence, you need to understand how some rocks can become magnetized.

Recall that Earth's magnetic field is much like that of a bar magnet. Geophysicists learned that Earth's magnetic field occasionally reverses *polarity*. That is, the north magnetic pole becomes the south magnetic pole, and vice versa. Scientists graphed these reversals of polarity going back millions of years. When Earth's magnetic field lines up in the same direction as the present magnetic field, it is said to have *normal polarity*. When the magnetic field lines up in the opposite direction, it is said to have *reverse polarity*.

As certain rocks form, they acquire the polarity that Earth's magnetic field has at the time. These rocks possess **paleomagnetism**. How does a rock become magnetized? Many igneous rocks contain magnetite, an iron-rich mineral. As the rock cools and hardens, the iron-rich mineral grains become magnetized in the same direction as the existing magnetic field. You can see this process in Figure 11. Once the rock has formed, its polarity remains frozen unless the rock is reheated above a certain temperature. But what if the rock is moved or if the magnetic pole changes its position? The rock's paleomagnetism does not change.

Scientists collected data on the paleomagnetism of the basalt that makes up the ocean floor. Ships towed instruments called magnetometers across the ocean floor. The data revealed a pattern of alternating strips of magnetized rock. Strips of rock with normal polarity alternated with strips of rock having reverse polarity. Scientists inferred that as new basalt forms along the mid-ocean ridges, it becomes magnetized according to the polarity of Earth's magnetic field at the time. The matching pattern of strips on both sides of a ridge, shown in Figure 12, is evidence that sea-floor spreading occurs.



What is paleomagnetism?

Customize for English Language Learners

Explain to students that there are many uses of the term *polar*, both in science and in everyday usage. For example, in magnetism, polarity refers to the magnetic poles. In chemistry,

polar molecules have partial charges. Polar also means diametrically opposite. Have students look up the various meanings of the term *polar* and use each meaning in a sentence.

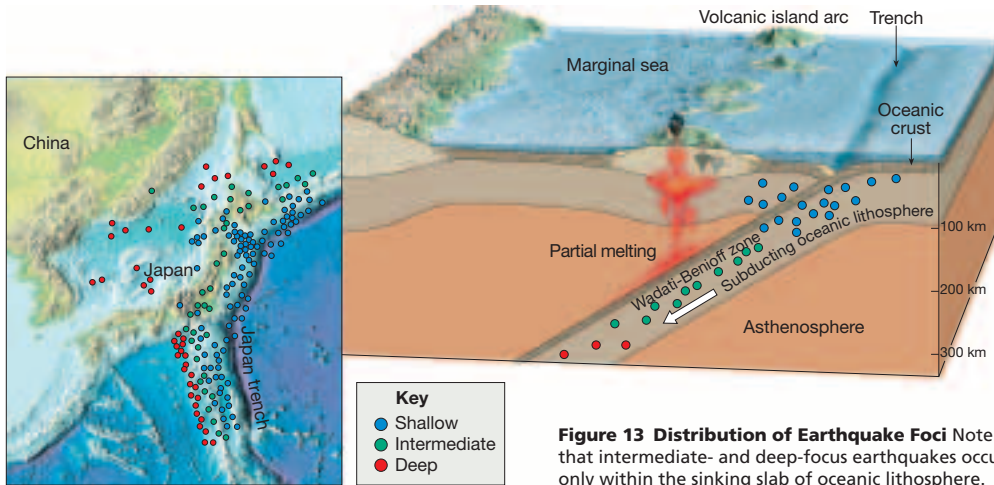
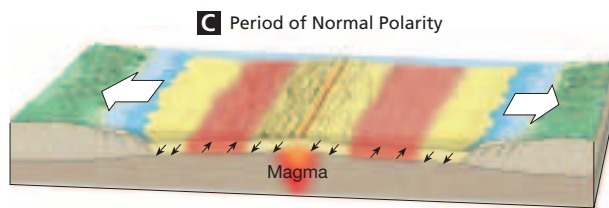


Figure 13 Distribution of Earthquake Foci Note that intermediate- and deep-focus earthquakes occur only within the sinking slab of oceanic lithosphere.

Earthquake Patterns More evidence for sea-floor spreading came from studies of the depth at which certain earthquakes occur. Scientists knew that there were many earthquakes in subduction zones. Two scientists, Kiyoo Wadati and Hugo Benioff, found a pattern when they plotted the depth of earthquakes in relation to their distance from deep-ocean trenches.

Shallow-focus earthquakes occur in and around a trench. Wadati and Benioff observed that intermediate-focus and deep-focus earthquakes occur in a belt about 50 kilometers thick. This belt extends through the lithosphere and deep into the asthenosphere. As you can see in Figure 13, the deeper the earthquake, the farther away its focus is from the deep-ocean trench. No earthquakes have been recorded below about 700 kilometers. At this depth the subducting slab of ocean floor has been heated enough to soften.

Scientists considered the pattern of earthquakes in Wadati-Benioff zones in relation to sea-floor spreading. The pattern was what scientists expected would result from subduction of the ocean floor. These data convinced scientists that slabs of ocean floor return to the mantle in subduction zones.



Facts and Figures

Random Reversals The random reversals of Earth's magnetic field have helped scientists to discover the ages of different sections of the ocean floor. Because the magnetic field reversals are random, any given period of time has a unique pattern of normal and reversed periods, like the unique bar code on packaged items at a store. This means that a scientist could sail across any part of the ocean, pulling a magnetometer behind the ship, and quickly

identify the age of the ocean floor from the unique pattern of normal and reversed periods. Though the reversals are random, the frequency of reversals changes over time. Currently, the field reverses several times per million years. One hundred million years ago, however, the field reversed more slowly, and there was a period of 35 million years where the field never reversed!

Build Science Skills

L2

Interpreting Diagrams Have students study Figure 13. Ask:

- From the map, identify the direction in which the sinking slab of oceanic lithosphere is moving. (from right to left)
- Locate Korea on the map. Why do you think Korea has relatively few earthquakes compared to Japan? (Korea is located far from ocean trenches; Japan is close to a trench.)
- What pattern does the map show? (Deeper earthquakes occur farther from the trench.) Be sure students can distinguish the blue dots from the green dots.
- What can geologists learn from this pattern? (They can use the plotted foci to track the plate's descent into the mantle.)

Visual, Logical

Answers to . . .

Figure 12 Both sides of the ocean plate are moving away from the ridge at equal rates, so the magnetized strips will be about equal in width.



Reading Checkpoint Paleomagnetism is the magnetization of a rock that reflects the polarity and direction of Earth's magnetic field at the time that the rock formed.

Section 9.2 (continued)

Build Reading Literacy **L1**

Refer to p. 530D in Chapter 19, which provides the guidelines for making inferences.

Making Inferences Have students read the section about the age of the ocean floor on this page. Ask: **What can you infer about the age of the ocean floor based on its distance from a mid-ocean ridge?** (You can infer that the age of the sea floor increases with increasing distance from the spreading center at an ocean ridge. The theory of sea-floor spreading states that new ocean lithosphere is created at ocean ridges, so the ocean floor should be younger closer to the ridges and older farther from the ridges.)

Verbal, Intrapersonal

3 ASSESS

Evaluate Understanding **L2**

To assess students' knowledge of section content, have them make flashcards for the vocabulary terms and the four lines of evidence supporting the plate tectonic theory. For each vocabulary term, the card should include a definition and an example, where applicable. For each line of evidence, the card should give an explanation of why it supports the theory and include an example. Students can use the cards to quiz one another.

Reteach **L1**

Have students explain in their own words why data produced by drilling into ocean-floor sediment provides evidence for sea-floor spreading.

Writing in Science

Students' paragraphs should explain that scientists drilled into the ocean floor in many locations to obtain rock samples that could be dated. The samples showed that the age of the ocean floor increases with distance from the mid-ocean ridges.

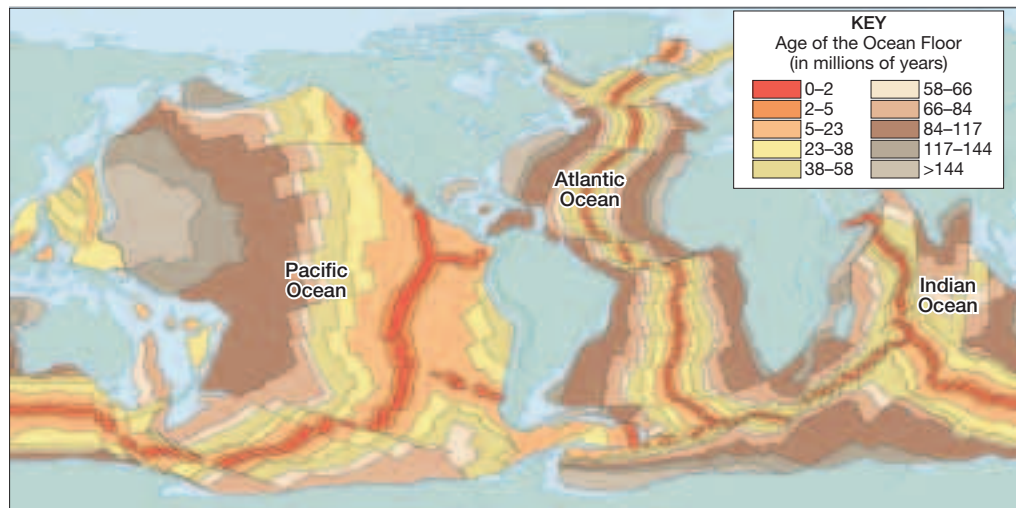


Figure 14 As the map shows, the youngest parts of the ocean floor lie along the mid-ocean ridges. The oldest parts of the ocean floor are found along the outer edges of ocean basins.

The Age of the Ocean Floor Drilling into sediment on the ocean floor and the crust beneath it provided some of the best evidence for sea-floor spreading. Beginning in 1968, the drilling ship *Glomar Challenger* collected data on both sides of mid-ocean ridges.

The data confirmed what the sea-floor spreading hypothesis predicted. The ocean floor is youngest along the central valley of the mid-ocean ridge. The ocean floor is oldest in subduction zones or near the edges of continents far from the ridge. The data also confirmed that none of the ocean floor is more than about 180 million years old. Older oceanic rock would have returned to the mantle through subduction.

Section 9.2 Assessment

Reviewing Concepts

1. Describe mid-ocean ridges and deep-ocean trenches.
2. Explain what occurs during sea-floor spreading.
3. List the evidence for sea-floor spreading.
4. What is a Wadati-Benioff zone?

Critical Thinking

5. **Inferring** Why are the oldest parts of the ocean floor less than 200 million years old?

6. **Applying Concepts** How do strips of magnetized rock on the ocean floor provide evidence of sea-floor spreading?
7. **Relating Cause and Effect** Would earthquakes occur at a depth of over 700 kilometers? Why or why not?

Writing in Science

Explanatory Paragraph Write a paragraph explaining how scientists learned the age of the ocean floor and how these data supported sea-floor spreading.

Section 9.2 Assessment

1. Mid-ocean ridges are part of a large, volcanic mountain range that winds through Earth's oceans; deep-ocean trenches are deep canyons in the ocean floor beneath which oceanic lithosphere sinks into the mantle through subduction.
2. During sea-floor spreading, magma erupts along a mid-ocean ridge to form new oceanic lithosphere. The ocean floor then moves away from the ridge, often toward a trench at the edge of the ocean basin.

3. magnetic stripes in ocean floor rock, earthquake patterns in subduction zones, and the fact that the age of the ocean floor increases with distance from mid-ocean ridges
4. A Wadati-Benioff zone is the belt in which earthquakes occur along a slab of subducting ocean floor.
5. The ocean floor is less than 200 million years old because that is the maximum amount of time it takes sea-floor spreading to move oceanic lithosphere from the mid-ocean ridges where it forms to the trenches where it is subducted.

6. Strips of ocean-floor basalt record the polarity of Earth's magnetic field at the time the rock formed. These strips form a pattern that is the same on both sides of the mid-ocean ridge. The pattern shows that ocean floor forms along mid-ocean ridges and then moves away from the ridge.
7. Earthquakes would not occur below 700 km because at that depth mantle rock is too soft and hot to store the elastic energy needed to cause an earthquake.