

These reading tools will help you learn the material in this chapter.

Word Parts

Prefixes Many scientific words are made up of word parts that come from Latin and Greek. You can figure out the meanings of unfamiliar science terms by looking at their word parts.

The words *Pangaea* and *Panthalassa* contain the prefix *pan-*. *Pan-* comes from a Greek word meaning "all." The root words *gaea* and *thalassa* come from Greek words meaning "land" and "ocean." *Pangaea* means "all lands," and *Panthalassa* means "all oceans."

Your Turn Prefixes found in this chapter include *paleo-*, *di-*, *trans-*, and *pan-*. As you read this chapter, make a table like the one started below. List words or terms that contain prefixes and give the meaning of each prefix.

WORD OR TERM	PREFIX	MEANING
paleomagnetism	paleo-	
divergent boundary	di-	

Fact, Hypothesis, or Theory?

Recognizing Facts, Hypotheses, and Theories A fact is a statement about the world that is based on observation. A hypothesis is a possible explanation that can be tested. A scientific theory is a model or explanation that ties together many hypotheses and observations.

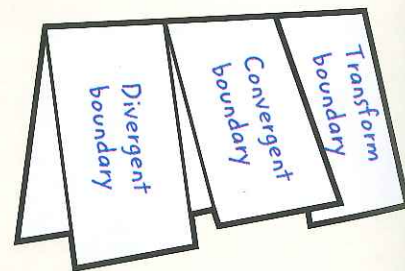
Your Turn Make a table like the one shown below. List statements of fact, hypotheses, and theories from Sections 1 and 2. Identify the type of statement, and write any language from the text that signals the type of statement.

STATEMENT	FACT, HYPOTHESIS, OR THEORY	KEY WORDS
	hypothesis	"proposed a hypothesis..."
	fact	"scientists found that..."
	theory	"lead to a theory," called _____

FoldNotes

Three-Panel Flip Chart FoldNotes are a fun way to help you learn and remember ideas that you encounter as you read. FoldNotes help you organize concepts and see the "big picture."

Your Turn Follow the instructions in Appendix A for making a three-panel flip chart. Label the first panel "Divergent boundary," the second "Convergent boundary," and the third "Transform boundary."



boundary." Open the appropriate flap to take notes about each type of boundary discussed in Section 2 and make a sketch.

For more information on how to use these and other tools, see Appendix A.

Key Ideas

- Summarize Wegener's hypothesis of continental drift.
- Describe the process of sea-floor spreading.
- Identify how paleomagnetism provides support for the idea of sea-floor spreading.
- Explain how sea-floor spreading provides a mechanism for continental drift.

Key Terms

continental drift
mid-ocean ridge
sea-floor spreading
paleomagnetism

Why It Matters

Evidence for continental drift was found in Earth's natural magnetism. This magnetism not only supports scientists' hypotheses, it also protects us all from the dangers of solar radiation.

One of the most exciting theories in Earth science began with observations made more than 400 years ago. As early explorers sailed the oceans of the world, they brought back information about new continents and their coastlines. Mapmakers used this information to chart the new discoveries and to make the first reliable world maps.

As people studied the maps, they were impressed by the similarity of the continental coastlines on either side of the Atlantic Ocean. The continents looked as though they would fit together like parts of a giant jigsaw puzzle. The east coast of South America, for example, seemed to fit perfectly into the west coast of Africa, as shown in **Figure 1**.

Wegener's Hypothesis

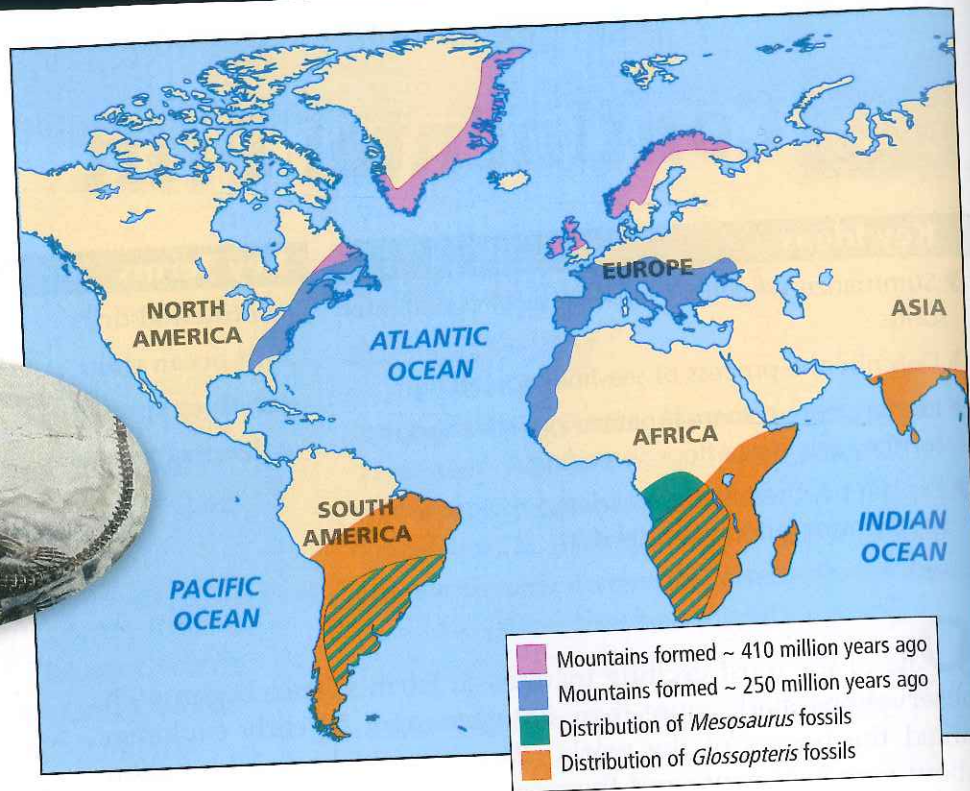
In 1912, a German scientist named Alfred Wegener (VAY guh nuhr) proposed a hypothesis that is now called **continental drift**. Wegener hypothesized that the continents once formed part of a single landmass called a *supercontinent*. According to Wegener, this supercontinent began breaking up into smaller continents during the Mesozoic Era (about 200 million years ago). Over millions of years, these continents drifted to their present locations. Wegener speculated that the crumpling of the crust in places may have produced mountain ranges such as the Andes on the western coast of South America.

Figure 1 Early explorers noticed that the coastlines of Africa and South America could fit together like puzzle pieces. *Can you identify any other continents that could fit together like puzzle pieces?*



continental drift the hypothesis that a single large landmass broke up into smaller landmasses to form the continents, which then drifted to their present locations

Figure 2 Fossils of *Mesosaurus*, such as the one shown below, were found in both South America and western Africa. Mountain chains of similar ages also exist on different continents, as shown in the map at right.



Fossil Evidence

In addition to seeing the similarities in the coastlines of the continents, Wegener found other evidence to support his hypothesis. He reasoned that if the continents had once been joined, fossils of the same plants and animals should be found in areas that had once been connected. Wegener knew that identical fossils of *Mesosaurus*, a small, extinct land reptile, had been found in both South America and western Africa. *Mesosaurus*, a fossil of which is shown in **Figure 2**, lived 270 million years ago (during the Paleozoic Era). Wegener knew that it was unlikely these reptiles had swum across the Atlantic Ocean. He also saw no evidence that land bridges had once connected the continents. So, he concluded that South America and Africa had been joined at one time in the past.

Evidence from Rock Formations

Geologic evidence also supported Wegener's hypothesis of continental drift. The ages and types of rocks in the coastal regions of widely separated areas, such as western Africa and eastern South America, matched closely. Mountain chains that ended at the coastline of one continent seemed to continue on other continents across the ocean, as shown in **Figure 2**. The Appalachian Mountains, for example, extend northward along the eastern coast of North America, and mountains of similar age and structure are found in Greenland, Scotland, and northern Europe. If the continents are assembled into a model supercontinent, the mountains of similar age fit together in continuous chains.

SCILINKS

www.scilinks.org
 Topic: Continental Drift
 Code: HQX0351

Climatic Evidence

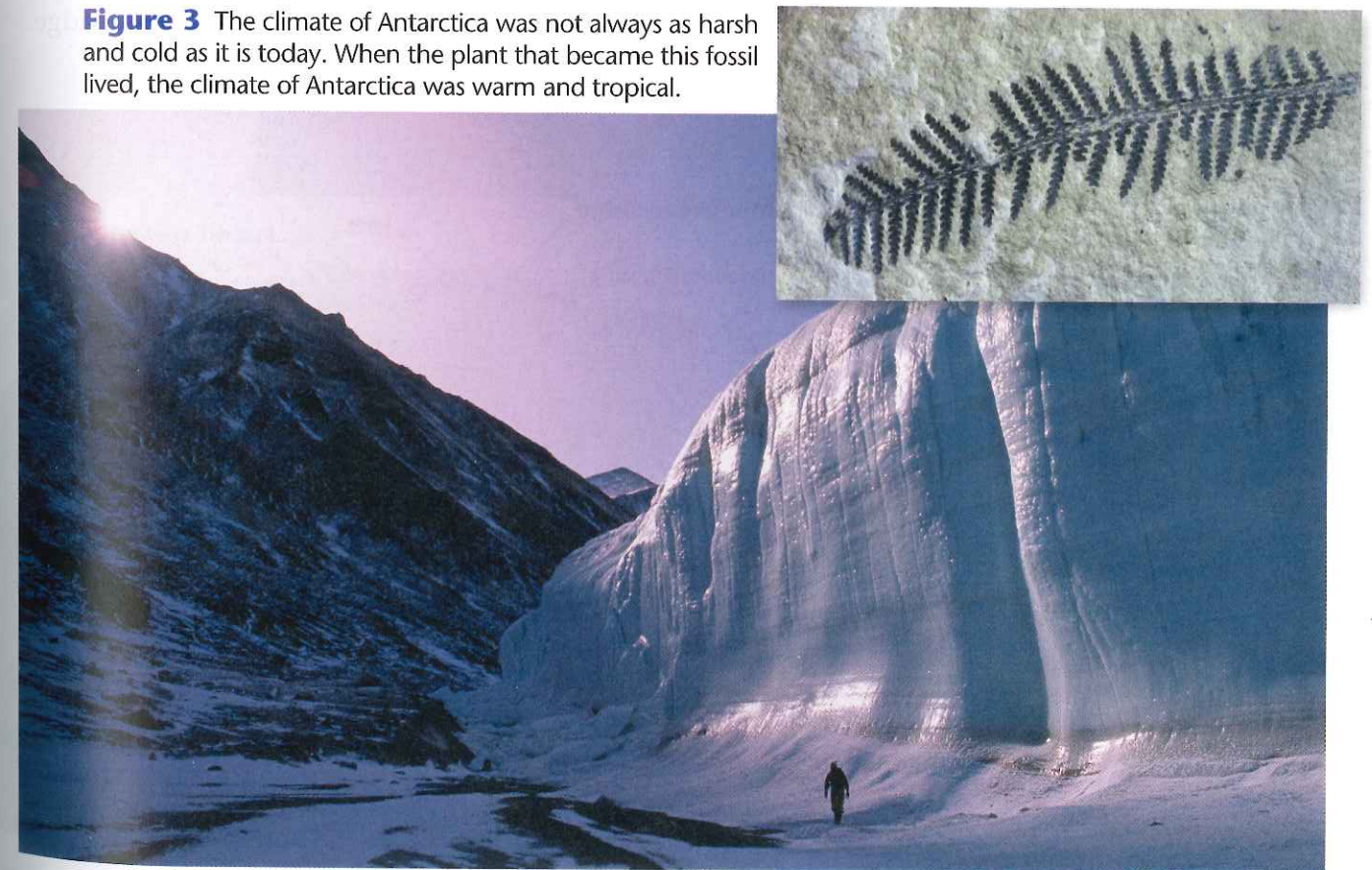
Changes in climatic patterns provided more evidence that the continents have not always been located where they are now. Geologists discovered layers of debris from ancient glaciers in southern Africa and South America. Today, those areas have climates that are too warm for glaciers to form. Other fossil evidence—such as the plant fossil shown in **Figure 3**—indicated that tropical or subtropical swamps covered areas that now have much colder climates. Wegener suggested that if the continents were once joined and positioned differently, evidence of climatic differences would be easy to explain.

Missing Mechanisms

Despite the evidence that supported the hypothesis of continental drift, Wegener's ideas were strongly opposed. Other scientists of the time rejected the mechanism proposed by Wegener to explain how the continents moved. Wegener suggested that the continents plowed through the rock of the ocean floor. However, this idea was shown to be physically impossible. Wegener spent the rest of his life searching for a mechanism that would gain scientific consensus. Unfortunately, Wegener died in 1930 before he identified a plausible explanation.

Reading Check Why did many scientists reject Wegener's hypothesis of continental drift? (See Appendix G for answers to Reading Checks.)

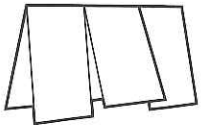
Figure 3 The climate of Antarctica was not always as harsh and cold as it is today. When the plant that became this fossil lived, the climate of Antarctica was warm and tropical.



READING TOOLBOX

Three-Panel Flip Chart

Make a three-panel flip chart. Label the panels "Fossil evidence," "Evidence from rock formations," and "Climatic evidence." Open the appropriate flap to take notes about evidence Wegener used to support his hypothesis.



Academic Vocabulary

mechanism (MEK uh NIZ uhm) any system or means by which something gets done



Figure 4 Black smokers are vents on the sea floor that form as hot, mineral-rich water rushes from the hot rock at mid-ocean ridges and mixes with the surrounding cold ocean water. This photo was taken from a submersible.

Mid-Ocean Ridges

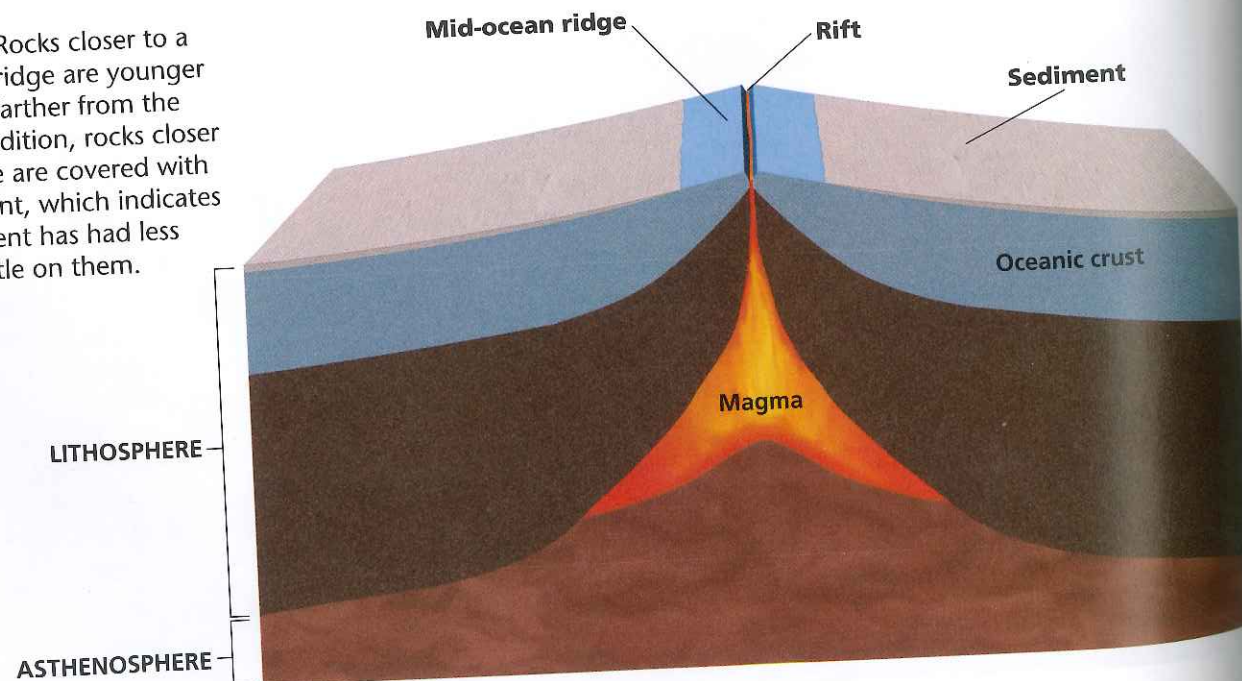
The evidence that Wegener needed to support his hypothesis was discovered nearly two decades after his death. The evidence lay on the ocean floor. In 1947, a group of scientists set out to map the Mid-Atlantic Ridge. The Mid-Atlantic Ridge is part of a system of **mid-ocean ridges**, which are undersea mountain ranges through the center of which run steep, narrow valleys. A special feature of mid-ocean ridges is shown in **Figure 4**. While studying the Mid-Atlantic Ridge, scientists noticed two surprising trends. First, they noticed that the sediment that covers the sea

floor is thinner closer to a ridge than it is farther from the ridge. This evidence suggests that sediment has been settling on the sea floor farther from the ridge for a longer time than it has been settling near the ridge. Scientists then examined the remains of tiny ocean organisms found in the sediment to date the sediment. The distribution of these organisms showed that the closer the sediment is to a ridge, the younger the sediment is. This evidence indicates that rocks closer to the ridge are younger than rocks farther from the ridge, as shown in **Figure 5**.

Second, scientists learned that the ocean floor is very young. While rocks on land are as much as 4 billion years old, none of the oceanic rocks are more than 200 million years old. Radiometric dating also showed evidence that sea-floor rocks closer to a mid-ocean ridge are younger than sea-floor rocks farther from a ridge.

mid-ocean ridge a long, undersea mountain chain that has a steep, narrow valley at its center, that forms as magma rises from the asthenosphere, and that creates new oceanic lithosphere (sea floor) as tectonic plates move apart

Figure 5 Rocks closer to a mid-ocean ridge are younger than rocks farther from the ridge. In addition, rocks closer to the ridge are covered with less sediment, which indicates that sediment has had less time to settle on them.



Sea-Floor Spreading

In the late 1950s, a geologist named Harry Hess suggested a new hypothesis. He proposed that the valley at the center of the ridge was a crack, or *rift*, in Earth's crust. At this rift, molten rock, or *magma*, from deep inside Earth rises to fill the crack. As the ocean floor moves away from the ridge, rising magma cools and solidifies to form new rock that replaces the ocean floor. This process is shown in **Figure 6**. During this process, named **sea-floor spreading** by geologist Robert Dietz, new ocean lithosphere forms as magma rises to Earth's surface and solidifies at a mid-ocean ridge. Hess suggested that if the ocean floor is moving, the continents might be moving, too. Hess thought that sea-floor spreading was the mechanism that Wegener had failed to find.

Still, Hess's ideas were only hypotheses. More evidence for sea-floor spreading would come years later, in the mid-1960s. This evidence would be discovered through **paleomagnetism**, the study of the magnetic properties of rocks.

Reading Check How does new sea floor form?

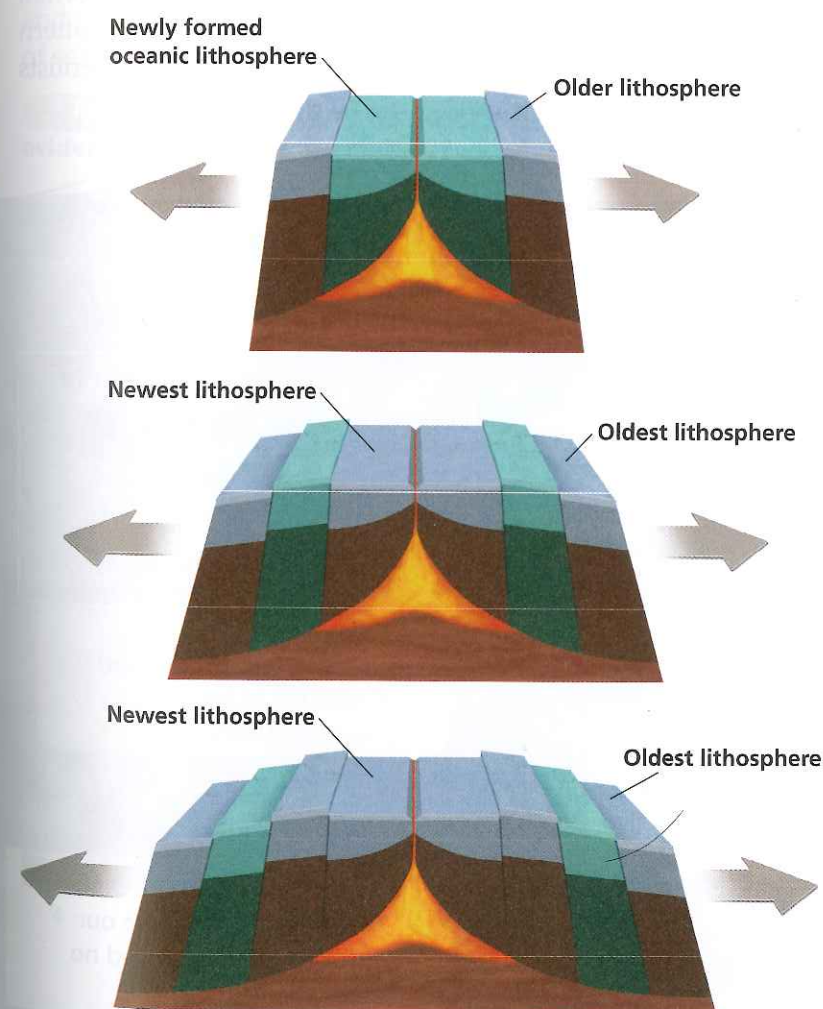


Figure 6 As the ocean floor spreads apart at a mid-ocean ridge, magma rises to fill the rift and then cools to form new rock. As this process is repeated over millions of years, new sea floor forms.

sea-floor spreading the process by which new oceanic lithosphere (sea floor) forms when magma rises to Earth's surface at mid-ocean ridges and solidifies, as older, existing sea floor moves away from the ridge

paleomagnetism the study of the alignment of magnetic minerals in rock, specifically as it relates to the reversal of Earth's magnetic poles; also the magnetic properties that rock acquires during formation

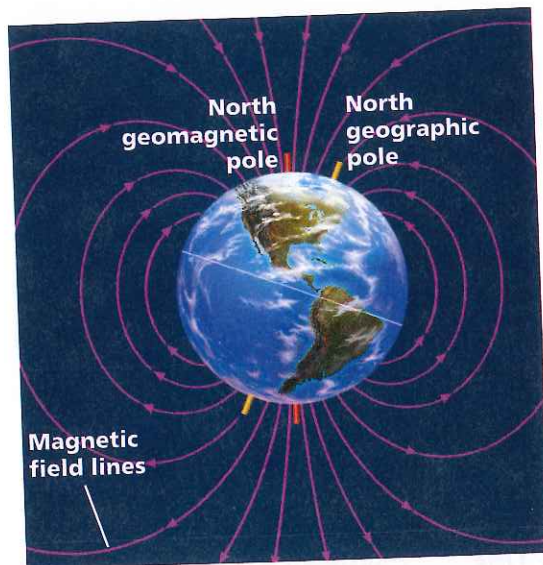


Figure 7 Earth acts as a giant magnet because of currents in Earth's core.

Paleomagnetism

If you have ever used a compass to determine direction, you know that Earth acts as a giant magnet. Earth has north and south geomagnetic poles, as shown in **Figure 7**. The compass needle aligns with the field of magnetic force that extends from one pole to the other.

As magma solidifies to form rock, iron-rich minerals in the magma align with Earth's magnetic field in the same way that a compass needle does. When the rock hardens, the magnetic orientation of the minerals becomes permanent. This residual magnetism of rock is called *paleomagnetism*.

Magnetic Reversals

Geologic evidence shows that Earth's magnetic field has not always pointed north, as it does now. Scientists have discovered rocks whose magnetic orientations point opposite to Earth's current magnetic field. Scientists have dated rocks of different magnetic polarities. All rocks with magnetic fields that point north, or *normal polarity*, are classified in the same time intervals. All rocks with magnetic fields that point south, or *reversed polarity*, also fall into specific time intervals. When scientists placed these periods of normal and reverse polarity in chronological order, they discovered a pattern of alternating normal and reversed polarity in the rocks. Scientists used this pattern to create the *geomagnetic reversal time scale*.

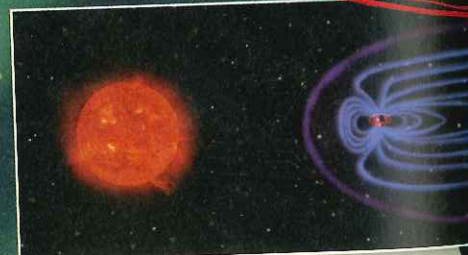
Why It Matters

Our Own Space Shield

Earth's magnetic field is not just an interesting topic for scientists. It makes life on Earth possible. Earth's magnetic field acts like a giant space shield, protecting our planet from the solar wind — electrically charged particles that stream away from the sun in all directions. Even with Earth's magnetic field in place, temporary increases in the strength of the solar wind can disrupt telecommunications systems and disable electric power grids. Without the magnetic field, Earth's atmosphere would be gradually swept away into the depths of space.



Auroras, commonly known as the northern and southern lights, are a sign that Earth's protective space shield is working.



The solar wind moves along Earth's magnetic field toward the poles, so auroras are commonly seen at high latitudes.

YOUR TURN

UNDERSTANDING CONCEPTS

What could happen to our atmosphere if Earth had no magnetic field?

WEIRD SCIENCE

Magnetic Symmetry

As scientists were learning about the age of the sea floor, they also were finding puzzling magnetic patterns on the ocean floor. The scientists used the geomagnetic reversal time scale to help them unravel the mystery of these magnetic patterns.

Scientists noticed that the striped magnetic pattern on one side of a mid-ocean ridge is a mirror image of the striped pattern on the other side of the ridge. These patterns are shown in **Figure 8**. When drawn on maps of the ocean floor, these patterns show alternating bands of normal and reversed polarity that match the geomagnetic reversal time scale. Scientists suggested that as new sea floor forms at a mid-ocean ridge, the new sea floor records reversals in Earth's magnetic field.

By matching the magnetic patterns on each side of a mid-ocean ridge to the geomagnetic reversal time scale, scientists could assign ages to the sea-floor rocks. The scientists found that the ages of sea-floor rocks were also symmetrical. The youngest rocks were at the center, and older rocks were farther away on either side of the ridge. The only place on the sea floor that new rock forms is at the rift in a mid-ocean ridge. Thus, the patterns indicate that new rock forms at the center of a ridge and then moves away from the center in opposite directions. Thus, the symmetry of magnetic patterns—and the symmetry of ages of sea-floor rocks—supports Hess's idea of sea-floor spreading.

Reading Check How are magnetic patterns in sea-floor rock evidence of sea-floor spreading?

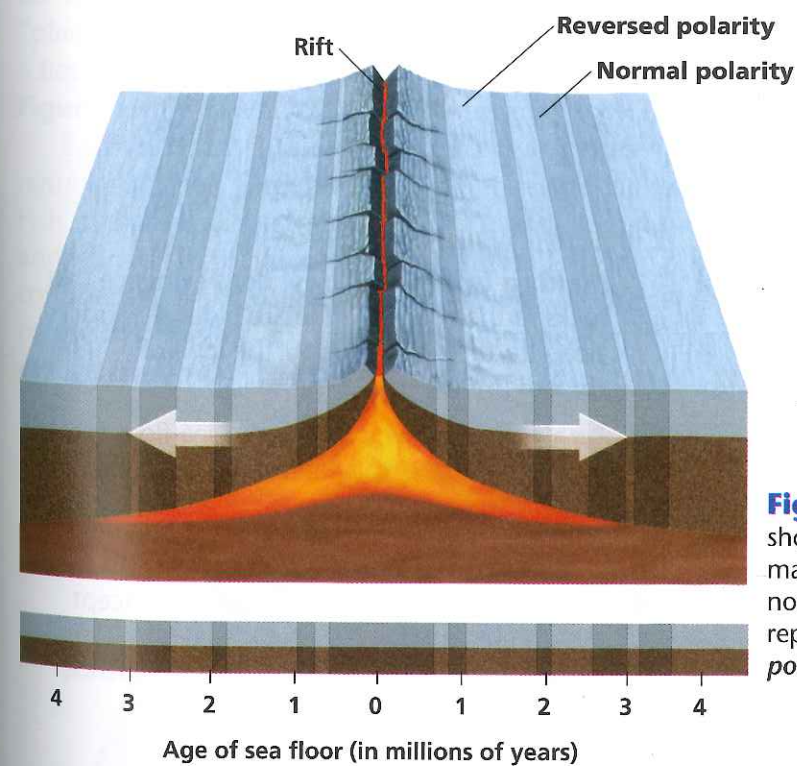


Figure 8 The stripes in the sea floor shown here illustrate Earth's alternating magnetic field. Dark stripes represent normal polarity, while lighter stripes represent reversed polarity. *What is the polarity of the rocks closest to the rift?*

Quick Lab

10 min

Making Magnets

Procedure

- Slide one end of a **bar magnet** down the side of a **5 inch iron nail** 10 times. Always slide the magnet in the same direction.
- Hold the nail over a small pile of **steel paper clips**. Record what happens.
- Slide the bar magnet back and forth 10 times down the side of the nail. Repeat step 2.

Analysis

- What was the effect of sliding the magnet down the nail in one direction? in different directions?
- How does this lab demonstrate the idea of polarity?

THINK central
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Figure 9 Scientists collected samples of these sedimentary rocks in California and used the magnetic properties of the samples to date the rocks by using the geomagnetic reversal time scale.



Wegener Redeemed

Another group of scientists discovered that the reversal patterns seen in rocks on the sea floor also appeared in rocks on land, such as those shown in **Figure 9**. The reversals in the land rocks matched the geomagnetic reversal time scale. Because the same pattern occurs in rocks of the same ages on both land and the sea floor, scientists became confident that magnetic patterns show changes over time. Thus, the idea of sea-floor spreading gained further favor in the scientific community.

Scientists reasoned that sea-floor spreading provides a way for the continents to move over Earth's surface. Continents are carried by the widening sea floor in much the same way that objects are carried by a conveyor belt. The molten rock from a rift cools, hardens, and then moves away in opposite directions on both sides of the ridge. Here, at last, was the mechanism that verified Wegener's hypothesis of continental drift.

Section 1 Review

Key Ideas

- Describe** the observation that first led to Wegener's hypothesis of continental drift.
- Summarize** the evidence that supports Wegener's hypothesis.
- Compare** sea-floor spreading with the formation of mid-ocean ridges.
- Explain** how scientists know that Earth's magnetic poles have reversed many times during Earth's history.
- Identify** how magnetic symmetry can be used as evidence of sea-floor spreading.
- Explain** how scientists date sea-floor rocks.

Critical Thinking

- Making Inferences** How does evidence that rocks farther from a ridge are older than rocks closer to the ridge support the idea of spreading?
- Analyzing Ideas** Explain how sea-floor spreading provides an explanation for how continents move over Earth's surface.

Concept Mapping

- Use the following terms to create a concept map: *continental drift, paleomagnetism, fossils, climate, sea-floor spreading, geologic evidence, supercontinent, and mid-ocean ridge.*

SECTION

2

The Theory of Plate Tectonics

Key Ideas

- Summarize the theory of plate tectonics.
- Identify and describe the three types of plate boundaries.
- List and describe three causes of plate movement.

Key Terms

plate tectonics
lithosphere
asthenosphere
divergent boundary
convergent boundary
transform boundary

Why It Matters

Plate tectonics is not just a scientific theory. Because of plate tectonics, you are able to enjoy the use of a cell phone, MP3 player, or any number of other electronic devices.

By the 1960s, evidence supporting continental drift and sea-floor spreading led to the development of a theory called *plate tectonics*. **Plate tectonics** is the theory that explains why and how continents move and is the study of the formation of features in Earth's crust.

How Continents Move

Earth's crust and the rigid, upper part of the mantle form a layer of Earth called the **lithosphere**. The lithosphere forms the thin outer shell of Earth. It is broken into several blocks, called *tectonic plates*, that ride on a deformable layer of the mantle called the *asthenosphere* in much the same way that blocks of wood float on water. The **asthenosphere** (as THEN uh sfire) is a layer of "plastic" rock just below the lithosphere. Plastic rock is a solid, not a liquid, but it is so hot that it flows very slowly, like putty does.

Figure 1 shows what tectonic plates may look like.

Earth's crust is classified into two types—*oceanic crust* and *continental crust*. Oceanic crust is dense and is made of rock that is rich in iron and magnesium. Continental crust has a low density and is made of rock that is rich in silica. Tectonic plates can include continental crust, oceanic crust, or both. The crust is carried along on the moving tectonic plates in the same way that passengers are carried by a bus.

plate tectonics the theory that explains how large pieces of the lithosphere, called *plates*, move and change shape

lithosphere the solid, outer layer of Earth that consists of the crust and the rigid upper part of the mantle

asthenosphere the solid, plastic layer of the mantle beneath the lithosphere

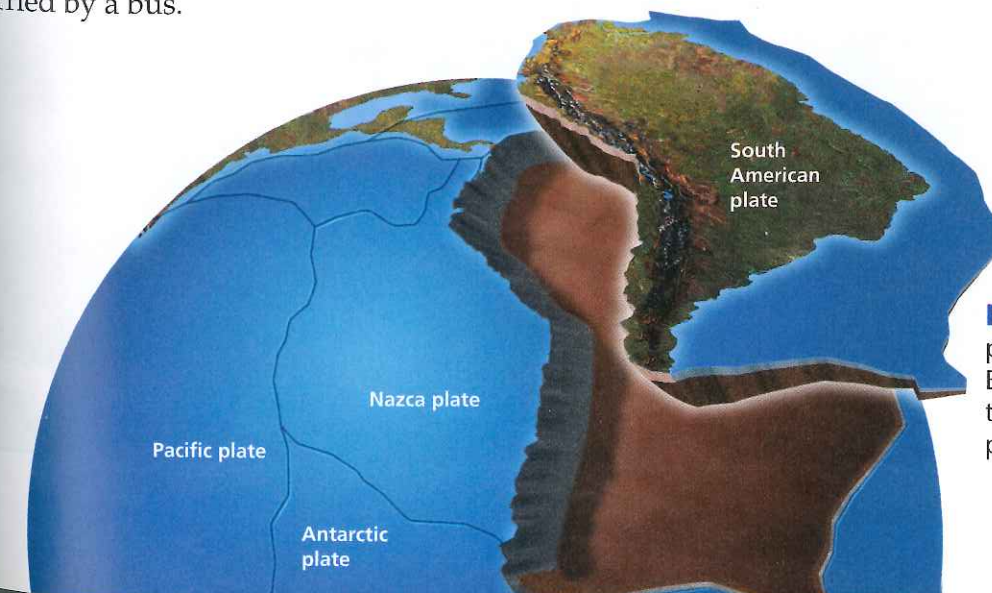


Figure 1 Tectonic plates fit together on Earth's surface like three-dimensional puzzle pieces.