Plate Tectonics

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Printed: September 26, 2014

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CHAPTER 1 Plate Tectonics

CHAPTER OUTLINE

Introduction

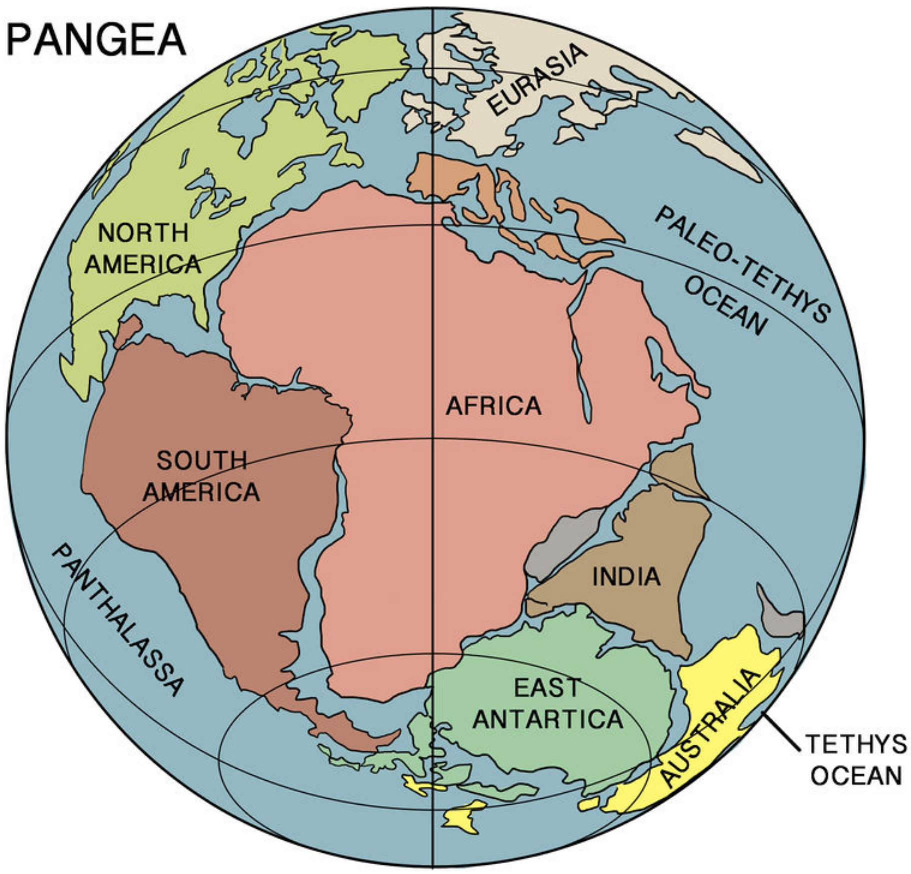
But it all seems so solid!

Besides flying around on a ball of rock —orbiting a giant ball of burning gas and spinning in circles about an axis —the ground you sit on is moving! Just as Copernicus, Kepler, and Galileo had trouble convincing people that Earth orbited the Sun when it clearly seemed that Earth was at the center of the universe and everything moved around it, early adherents to the idea that continents could move had to fight against, well, common sense. Over the past century the idea that continents could move was proposed, studied, abandoned, and finally accepted.

We'll start this concept with a field trip back in time to the scientists that developed plate tectonics theory. First, we'll visit Wegener, and then we'll get aboard ship to learn about seafloor spreading. Finally, we'll travel around western North America to see the features created by the different types of plate boundaries there.

1.1 Continental Drift

- Identify the evidence Wegener had in support of his continental drift hypothesis.
- Apply the steps of scientific method to Wegener's scientific investigation.



"Doesn't the east coast of South America fit exactly against the west coast of Africa, as if they had once been joined? This is an idea I'll have to pursue." - Alfred Wegener to his future wife, December, 1910.

We can't really get into Alfred Wegner's head, but we can imagine that he started his investigations by trying to answer this question: Why do the continents of Africa and South America appear to fit together so well? Is it an accident that they do, or is there some geological reason?

Wegener's Idea

Alfred Wegener, born in 1880, was a meteorologist and explorer. In 1911, Wegener found a scientific paper that listed identical plant and animal fossils on opposite sides of the Atlantic Ocean. Intrigued, he then searched for and found other cases of identical fossils on opposite sides of oceans. The explanation put out by the scientists of the day was that land bridges had once stretched between these continents.

Instead, Wegener pondered the way Africa and South America appeared to fit together like puzzle pieces. Other scientists had suggested that Africa and South America had once been joined, but Wegener was the idea's most dogged supporter. Wegener amassed a tremendous amount of evidence to support his hypothesis that the continents had once been joined.

Imagine that you're Wegener's colleague. What sort of evidence would you look for to see if the continents had actually been joined and had moved apart?

Wegener's Evidence

Here is the main evidence that Wegener and his supporters collected for the continental drift hypothesis:

- The continents appear to fit together.
- Ancient fossils of the same species of extinct plants and animals are found in rocks of the same age but are on continents that are now widely separated (**Figure** 1.1). Wegener proposed that the organisms had lived side by side, but that the lands had moved apart after they were dead and fossilized. His critics suggested that the organisms moved over long-gone land bridges, but Wegener thought that the organisms could not have been able to travel across the oceans.
  - Fossils of the seed fern *Glossopteris* were too heavy to be carried so far by wind.
  - *Mesosaurus* was a swimming reptile, but could only swim in fresh water.
  - *Cynognathus* and *Lystrosaurus* were land reptiles and were unable to swim.

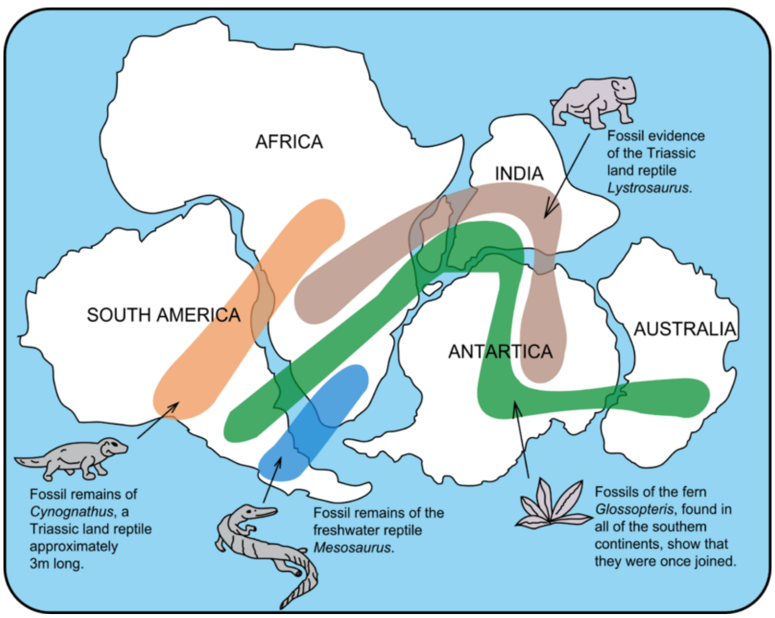


FIGURE 1.1

Wegener used fossil evidence to support his continental drift hypothesis. The fossils of these organisms are found on lands that are now far apart.

- Identical rocks, of the same type and age, are found on both sides of the Atlantic Ocean. Wegener said the rocks had formed side by side and that the land had since moved apart.
- Mountain ranges with the same rock types, structures, and ages are now on opposite sides of the Atlantic Ocean. The Appalachians of the eastern United States and Canada, for example, are just like mountain ranges in eastern Greenland, Ireland, Great Britain, and Norway (**Figure** 1.2). Wegener concluded that they formed as a single mountain range that was separated as the continents drifted.

- Grooves and rock deposits left by ancient glaciers are found today on different continents very close to the Equator. This would indicate that the glaciers either formed in the middle of the ocean and/or covered most

FIGURE 1.2
The similarities between the Appalachian and the eastern Greenland mountain ranges are evidences for the continental drift hypothesis.

of the Earth. Today, glaciers only form on land and nearer the poles. Wegener thought that the glaciers were centered over the southern land mass close to the South Pole and the continents moved to their present positions later on.
- Coral reefs and coal-forming swamps are found in tropical and subtropical environments, but ancient coal seams and coral reefs are found in locations where it is much too cold today. Wegener suggested that these creatures were alive in warm climate zones and that the fossils and coal later drifted to new locations on the continents. An animation showing that Earth's climate belts remain in roughly the same position while the continents move is seen here: http://www.scotese.com/paleocli.htm .
- Wegener thought that mountains formed as continents ran into each other. This got around the problem of the leading hypothesis of the day, which was that Earth had been a molten ball that bulked up in spots as it cooled (the problem with this idea was that the mountains should all be the same age and they were known not to be). An animation showing how the continents split up can be found here: http://www.exploratorium.edu/origins/antarctica/ideas/gondwana2.html .

Summary

- Alfred Wegener did some background reading and made an observation.
- Wegener then asked an important question and set about to answer it.
- He collected a great deal of evidence to support his idea. Wegener's evidence included the fit of the continents, the distribution of ancient fossils, the placement of similar rocks and structures on the opposite sides of oceans, and indicators of ancient climate found in locations where those climates do not exist today.

Explore More

Use this resource to answer the questions that follow.

https://www.youtube.com/watch?v=T1-cES1Ekto

1. What happened in 1910?
2. What happened in 1915?
3. Why was Wegener thought to be "a crazy man?" What did his fellow scientists want him to do?

4. Without a how and why, he had a(n) __________, but with evidence he could have a(n) __________.
5. What happened in 1930?
6. What happened 30 years later?

Explore More Answers

1. Alfred Wegener noticed that the continents looked like the pieces of a broken puzzle.
2. He called his idea continental drift; it caused a rift in the scientific community. The other scientists thought he was way off base.
3. He had no idea for how or why the continents could move. They wanted him to come up with a plausible idea for how and why this could happen.
4. hypothesis; theory
5. Wegener got caught in a blizzard in Greenland and he was buried there.
6. Plate tectonics theory came about and brought continental drift back to light.

Review

1. How did Wegener become interested in the idea that continents could move?
2. What did he need to do to explore the question and make it into a reasonable hypothesis?
3. How did Wegener use fossil evidence to support his hypothesis?
4. How did Wegener use climate evidence from rocks to support his hypothesis?

Review Answers

1. He saw that the coastlines of Africa and South America appeared to fit together like puzzle pieces and he thought that if they had once been joined they must have since moved apart.
2. He needed more evidence. He also needed a mechanism for how the continents could move.
3. Fossils of the same organism type were found on continents on other sides of the Atlantic Ocean. He said the continents were joined when the animals had lived.
4. Rocks that formed in environments that are found in certain climates now, like coal or coral reefs, are found in very different locations so Wegener thought they had moved on their continents.

1.2 Wegener and the Continental Drift Hypothesis

- Define the continental drift hypothesis.
- Analyze why the continental drift hypothesis was not accepted by the majority of scientists in Wegener's day.

"Scientists still do not appear to understand sufficiently..."

"...that all earth sciences must contribute evidence toward unveiling the state of our planet in earlier times, and that the truth of the matter can only be reached by combing all this evidence. ... It is only by combing the information furnished by all the earth sciences that we can hope to determine 'truth' here, that is to say, to find the picture that sets out all the known facts in the best arrangement and that therefore has the highest degree of probability. Further, we have to be prepared always for the possibility that each new discovery, no matter what science furnishes it, may modify the conclusions we draw." - Alfred L. Wegener, *The Origins of Continents and Oceans*, first published in 1915.

Wegener put together a tremendous amount of evidence that the continents had been joined. He advocated using scientific evidence to find the "truth." As his colleague, are you convinced? Let's explore.

Wegener's Continental Drift Hypothesis

Wegener put his idea and his evidence together in his book *The Origin of Continents and Oceans*, first published in 1915. New editions with additional evidence were published later in the decade. In his book he said that around 300 million years ago the continents had all been joined into a single landmass he called Pangaea, meaning "all earth" in ancient Greek. The supercontinent later broke apart and the continents having been moving into their current positions ever since. He called his hypothesis **continental drift**.

The Problem with the Hypothesis

Wegener's idea seemed so outlandish at the time that he was ridiculed by other scientists. What do you think the problem was? To his colleagues, his greatest problem was that he had no plausible mechanism for how the continents could move through the oceans. Based on his polar experiences, Wegener suggested that the continents were like icebreaking ships plowing through ice sheets. The continents moved by centrifugal and tidal forces. As Wegener's colleague, how would you go about showing whether these forces could move continents? What observations would you expect to see on these continents?

FIGURE 1.3

Alfred Wegener suggested that continental drift occurred as continents cut through the ocean floor, in the same way as this icebreaker plows through sea ice.

FIGURE 1.4

Early hypotheses proposed that centrifugal forces moved continents. This is the same force that moves the swings outward on a spinning carnival ride.

Scientists at the time calculated that centrifugal and tidal forces were too weak to move continents. When one scientist did calculations that assumed that these forces were strong enough to move continents, his result was that if Earth had such strong forces the planet would stop rotating in less than one year. In addition, scientists also thought that the continents that had been plowing through the ocean basins should be much more deformed than they are.

Wegener answered his question of whether Africa and South America had once been joined. But a hypothesis is rarely accepted without a mechanism to drive it. Are you going to support Wegener? A very few scientists did, since his hypothesis elegantly explained the similar fossils and rocks on opposite sides of the ocean, but most did not.

Mantle Convection

Wegener had many thoughts regarding what could be the driving force behind continental drift. Another of Wegener's colleagues, Arthur Holmes, elaborated on Wegener's idea that there is thermal convection in the mantle.

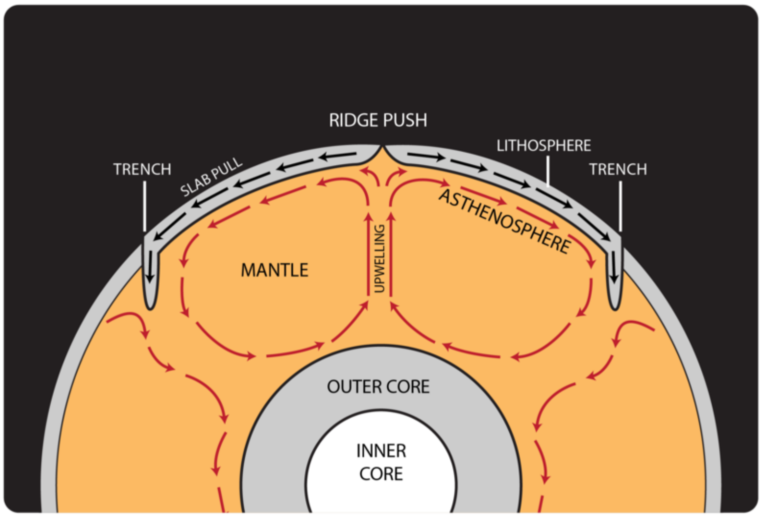


FIGURE 1.5
Thermal convection occurs as hot rock in the deep mantle rises towards the Earth's surface. This rock then spreads out and cools, sinking back towards the core, where it can be heated again. This circulation of rock through the mantle creates convection cells.

In a **convection cell**, material deep beneath the surface is heated so that its density is lowered and it rises. Near the surface it becomes cooler and denser, so it sinks. Holmes thought this could be like a conveyor belt. Where two adjacent convection cells rise to the surface, a continent could break apart with pieces moving in opposite directions. Although this sounds like a great idea, there was no real evidence for it, either.

Alfred Wegener died in 1930 on an expedition on the Greenland icecap. For the most part the continental drift idea was put to rest for a few decades, until technological advances presented even more evidence that the continents moved and gave scientists the tools to develop a mechanism for Wegener's drifting continents. Since you're on a virtual field trip, you get to go along with them as well.

Summary

- Alfred Wegener published his idea that the continents had been joined as a single landmass, which he called Pangaea, about 300 million years ago.
- Wegener's idea was mostly ridiculed, in part because Wegener could not develop a plausible mechanism for continents moving through oceanic crust.
- Calculations showed that his idea about centrifugal and tidal forces powering the continents could not be right.
- Wegener also thought about mantle convection an idea expanded on by Arthur Holmes as the driving force for continental drift. There was no evidence available to support the idea at the time.

Explore More

Use these resources to answer the questions that follow.

https://www.youtube.com/watch?v=MEh4B1Pv8YE

1. What did Alfred Wegener suggest?
2. What did Wegener see on a map? What else did he notice?
3. What did he infer from this? (The first time the video mentions time it says 3 million years ago, which is off by almost two orders magnitude, but it is correct later.)
4. When did Pangaea begin to divide? What did it divide into?
5. Why wasn't Wegener's idea not accepted by most scientists?
6. What was Harry Hess doing 30 years later and what did he discover?
7. What was Hess' hypothesis?
8. What are tectonic plates made of?

Explore More Answers

1. Wegener suggested that the continents were moving.
2. South America and Africa could fit together and fossils in both places matched. Some coal beds and mountain ranges across the Atlantic matched up.
3. All the continents were once together as one giant continent called Pangaea.
4. 200 million years ago; two continents Laurasia and Gondwana
5. He didn't have a force to move the continents.
6. Hess was mapping the Atlantic ocean floor and discovered the Mid-Atlantic Ridge.
7. Older rocks subducted into the mantle and brought the plate with it so that it spread.
8. The crust and upper mantle.

Review

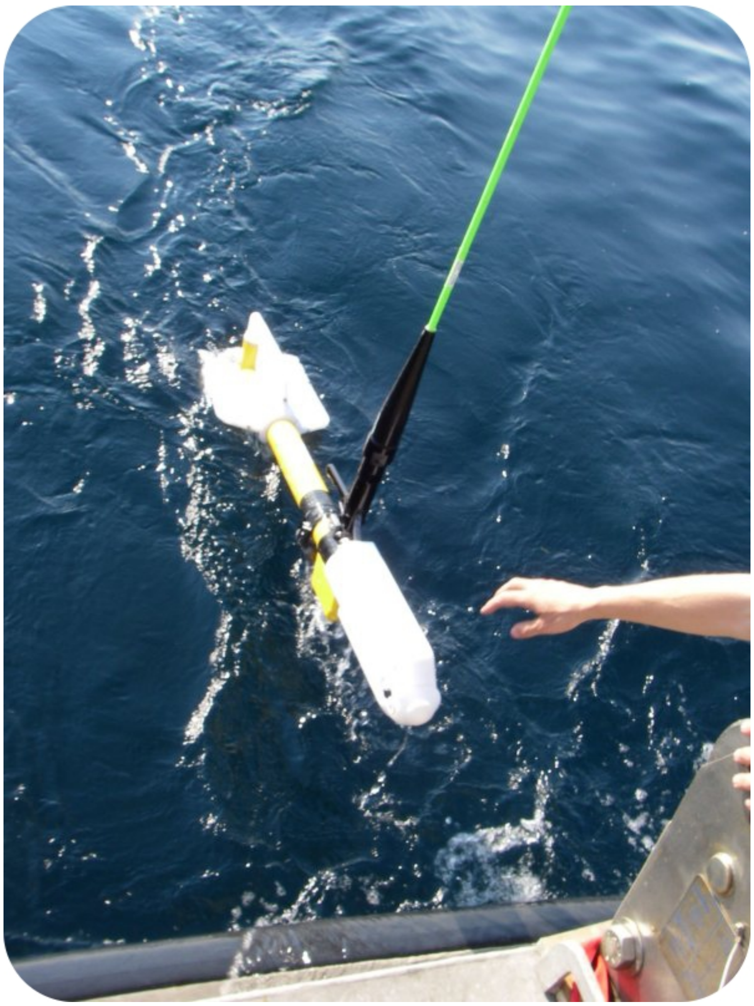
1. Describe the continental drift hypothesis.
2. Why did scientists reject Wegener's idea? What was needed for them to accept it?
3. Are there some ideas (hypotheses, theories) that have a great deal of evidence to support them, yet are not accepted by many people?

Review Answers

1. All of Earth's continents were joined together in one giant landmass that broke apart. The continents have been moving into their current positions ever since.
2. He had no plausible mechanism for how the solid continents could move through the solid ocean basins. They needed a mechanism.
3. Yes there are. Wegener's continental drift had a lot of evidence but it was not accepted. Today, although nearly all scientists accept the theory that our climate is changing due to human activities, a lot of lay people do not believe it.

1.3 Magnetic Polarity Evidence for Continental Drift

- Identify how magnetic polarity evidence supports the continental drift hypothesis.



"The Wegener hypothesis has been so stimulating and has such fundamental implications in geology..."

"...as to merit respectful and sympathetic interest from every geologist. Some striking arguments in his favor have been advanced, and it would be foolhardy indeed to reject any concept that offers a possible key to the solution of profound problems in the Earth's history." - Chester R. Longwell, "Some Thoughts on the Evidence for Continental Drift," 1944

Wegener and his supporters did all they could do to find evidence to support continental drift. But without a mechanism the idea would not be accepted. What was needed was the development of technologies that would allow scientists to find more evidence for the idea and help them describe a mechanism. But first, they would find still more evidence that the continents had moved.

Magnetic Polarity Evidence

The next breakthrough in the development of the theory of plate tectonics came two decades after Wegener's death. **Magnetite** crystals are shaped like a tiny bar magnet. As basalt lava cools, the magnetite crystals line up in the magnetic field like tiny magnets. When the lava is completely cooled, the crystals point in the direction of magnetic north pole at the time they form. How do you expect this would help scientists see whether continents had moved or not?

FIGURE 1.6
Magnetite crystals.

As a Wegener supporter, (and someone who is omniscient), you have just learned of a new tool that may help you. A **magnetometer** is a device capable of measuring the magnetic field intensity. This allows you to look at the magnetic properties of rocks in many locations. First, you're going to look at rocks on land. Which rocks should you seek out for study?

Magnetic Polarity on the Same Continent with Rocks of Different Ages

Geologists noted important things about the magnetic polarity of different aged rocks on the same continent:

- Magnetite crystals in fresh volcanic rocks point to the current magnetic north pole (**Figure** 1.7) no matter what continent or where on the continent the rocks are located.

- Older rocks that are the same age and are located on the same continent point to the same location, but that location is not the current north magnetic pole.
- Older rocks that are of different ages do not point to the same locations or to the current magnetic north pole.

In other words, although the magnetite crystals were pointing to the magnetic north pole, the location of the pole seemed to wander. Scientists were amazed to find that the north magnetic pole changed location over time (**Figure** 1.8).

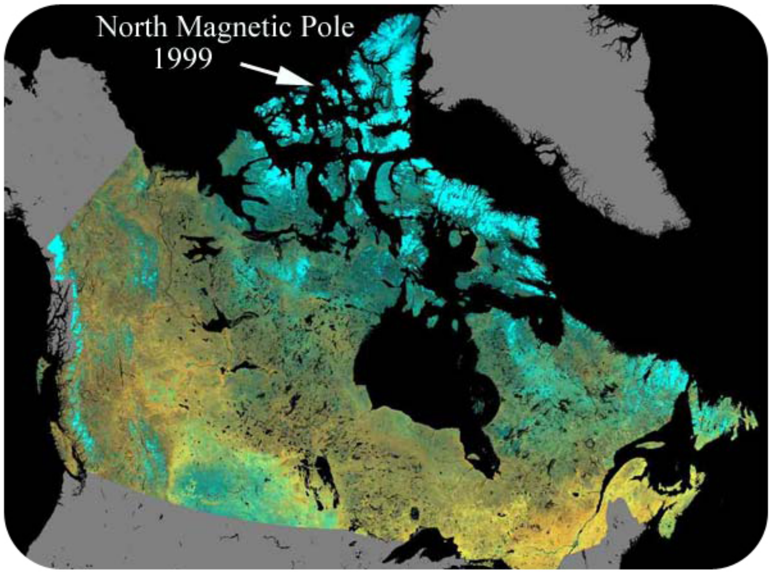


FIGURE 1.7
Earth's current north magnetic pole is in northern Canada.

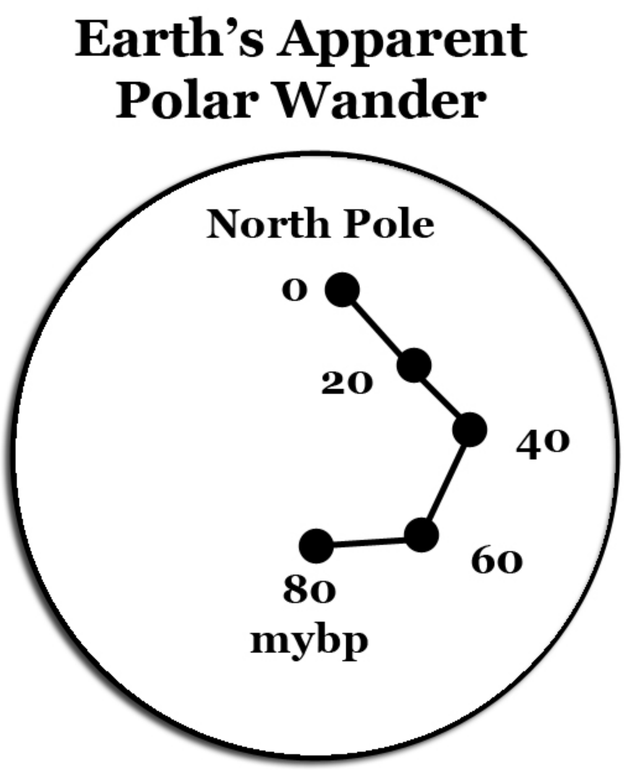


FIGURE 1.8
The location of the north magnetic north pole 80 million years before present (mybp), then 60, 40, 20, and now.

Can you figure out the three possible explanations for this? They are:

1. The continents remained fixed and the north magnetic pole moved.
2. The north magnetic pole stood still and the continents moved.
3. Both the continents and the north pole moved.

Magnetic Polarity on Different Continents with Rocks of the Same Age

How do you figure out which of those three possibilities is correct? You decide to look at magnetic rocks on different continents. Geologists noted that for rocks of the same age but on different continents, the little magnets pointed to different magnetic north poles.

- 400 million-year-old magnetite in Europe pointed to a different north magnetic pole than magnetite of the same age in North America.
- 250 million years ago, the north poles were also different for the two continents.

Now look again at the three possible explanations. Only one can be correct. If the continents had remained fixed while the north magnetic pole moved, there must have been two separate north poles. Since there is only one north pole today, what is the best explanation? The only reasonable explanation is that the magnetic north pole has remained fixed but that the continents have moved.

Wegener was Right!

How does this help you to provide evidence for continental drift? To test the idea that the pole remained fixed but the continents moved, geologists fitted the continents together as Wegener had done. It worked! There has only been one magnetic north pole and the continents have drifted (**Figure** 1.9). They named the phenomenon of the magnetic pole that seemed to move but actually did not **apparent polar wander**.

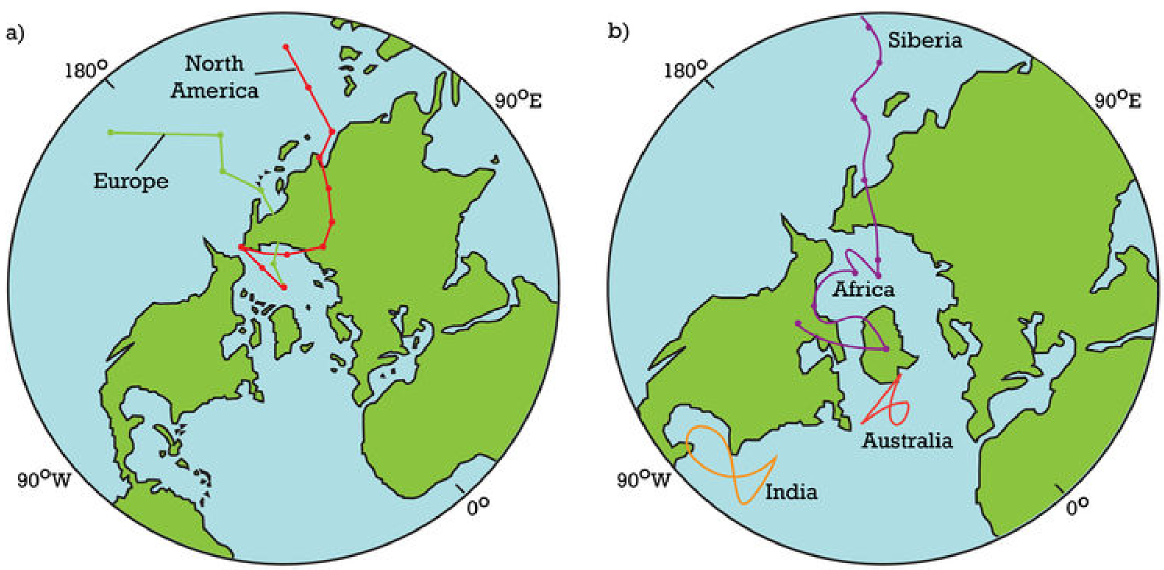


FIGURE 1.9
On the left: The apparent north pole for Europe and North America if the continents were always in their current locations. The two paths merge into one if the continents are allowed to drift.

This evidence for continental drift gave geologists renewed interest in understanding how continents could move about on the planet's surface.

Summary

- Using magnetic evidence found on a single continent in the 1950s, scientists showed that either the north magnetic pole was in a different spot in Earth's past or that the continents had moved.
- When they added magnetic evidence from a second continent, they showed that in the past there had either been two magnetic north poles or the continents had moved.
- Since there is only one magnetic north pole today, they concluded that the simplest explanation is that the continents have moved.

Explore More

Use the resource below to answer the questions that follow.

- **Apparent Polar Wander** at http://www.grossmont.edu/garyjacobson/animations.htm

1. Explain what appears to be occurring at the North Pole.
2. What direction is the pole moving?
3. Describe the movement of the South Pole.
4. What direction is the South Pole moving?

Explore More Answers

1. The North Pole appears to be moving.
2. north-northwest
3. It is moving up Antarctica.
4. northwest

Review

1. What is apparent polar wander?
2. How does magnetic evidence from one continent show that either the north magnetic pole has moved or the continents have moved?
3. How does magnetic evidence from two continents show that the continents have moved?

Review Answers

1. The magnetic pole appears to be in different positions, as if it were wandering across the land, but actually the land has moved.
2. Magnetite is a magnetic crystal that lines up with the magnetic field. It crystallizes from fluid lava and points to the north magnetic pole as the lava cools. If it points to a spot that is not where the pole is it means that the land the lava flow is on has moved.
3. Magnetite crystals from different aged rocks point in different locations. By using this scientists can determine where the magnetic pole was located at the time the rocks cooled. This information can be used to reconstruct where the continents would have been if the pole was stationary.

1.4 Bathymetric Evidence for Seafloor Spreading

- Describe how seafloor bathymetry allows scientists to study features of the seafloor.
- Identify features of the seafloor and describe how they provide evidence for the theory of plate tectonics.

Let's go to sea!

To understand what came next, we need to go to sea aboard a research vessel. From the photo you can probably tell that a research vessel is no cruise ship. It's a lot smaller, and community spaces are filled with science labs, not swimming pools. The food ranges from barely edible to tasty and filling, but is rarely sumptuous. But with a research vessel we can gather data to explore the seafloor. Let's go on one now!

Life at Sea

We'll go out on the research vessel (R/V in ship-speak) Atlantis, owned by the US Navy and operated by the Woods Hole Oceanographic Institution for the oceanographic community.

The Atlantis has six science labs and storage spaces, precise navigation systems, seafloor-mapping sonar and satellite communications. Most importantly, the ship has all of the heavy equipment necessary to deploy and operate Alvin, the manned research submersible.

The ship has 24 bunks available for scientists, including two for the chief scientists. The majority of these bunks are below waterline, which makes for good sleeping in the daytime. Ship time is really expensive research, so vessels operate all night and so do the scientists. Your "watch", as your time on duty is called, may be 12-4, 4-8 or 8-12 –that's AM and PM. Alternately, if you're on the team doing a lot of diving in Alvin, you may just be up during the day. If you're mostly doing operations that don't involve Alvin, you may just be up at night. For safety reasons, Alvin is deployed and recovered only in daylight.

FIGURE 1.10
Alvin is deployed from the stern of the R/V Atlantis.

Scientists come from all over to meet a research ship in a port. An oceanographer these days doesn't need to be near the ocean, he or she just needs to have access to an airport!

Let's begin this cruise in Woods Hole, Massachusetts, Atlantis' home port. Our first voyage will be out to the Mid-Atlantic Ridge. Transit time to the research site can take days. By doing this virtually, we don't have to spend days in transit to our research site, and we don't have to get seasick!

As we head to the site, we will run the echo sounder. Let's see what we can find!

Echo Sounding

The people who first mapped the seafloor were aboard military vessels during World War II. As stated in the Earth as a Planet chapter, echo sounders used sound waves to search for submarines, but also produced a map of seafloor depths. Depth sounding continued in earnest after the war. Scientists pieced together the ocean depths to produce bathymetric maps of the seafloor. During WWII and in the decade or so later, echo sounders had only one beam, so they just returned a line showing the depth beneath the ship. Later echo sounders sent out multiple beams and could create a bathymetric map of the seafloor below.

We will run a multi-beam echo sounder as we go from Woods Hole out to the Mid-Atlantic Ridge.

Features of the Seafloor

Although they expected an expanse of flat, featureless plains, scientists were shocked to find tremendous features like mountain ranges, rifts, and trenches. This work continues on oceanographic research vessels as they sail across the seas today. The map in the **Figure** 1.11 is a modern map with data from several decades.

The major features of the ocean basins and their colors on the map in **Figure** 1.11 include:

- **mid-ocean ridges**: these features rise up high above the deep seafloor as a long chain of mountains, e.g. the light blue gash in middle of Atlantic Ocean.
- rift zones: in the middle of the mid-ocean ridges is a rift zone that is lower in elevation than the mountains surrounding it.

- deep sea **trenches**: these features are found at the edges of continents or in the sea near chains of active volcanoes, e.g. the very deepest blue, off of western South America.
- **abyssal plains**: these features are flat areas, although many are dotted with volcanic mountains, e.g. consistent blue off of southeastern South America.

See if you can identify each of these features in **Figure** 1.11.

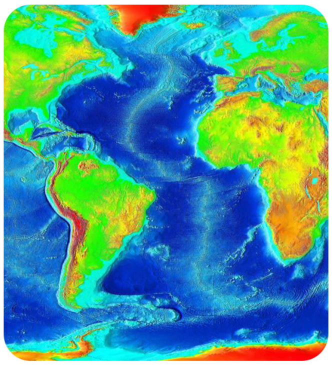


FIGURE 1.11
A modern map of the southeastern Pacific and Atlantic Oceans.

When they first observed these bathymetric maps, scientists wondered what had formed these features. It turns out that they were crucial for fitting together ideas about seafloor spreading.

Continental Margin

As we have seen, the ocean floor is not flat: mid-ocean ridges, deep sea trenches, and other features all rise sharply above or plunge deeply below the abyssal plains. In fact, Earth's tallest mountain is Mauna Kea volcano, which rises 10,203 m (33,476 ft.)meters) from the Pacific Ocean floor to become one of the volcanic mountains of Hawaii. The deepest canyon is also on the ocean floor, the Challenger Deep in the Marianas Trench, 10,916 m (35,814 ft).

The **continental margin** is the transition from the land to the deep sea or, geologically speaking, from continental crust to oceanic crust. More than one-quarter of the ocean basin is continental margin. (**Figure** 1.12).

Summary

- Much of what went into developing plate tectonics theory involved work done at sea.
- Echo sounders used to search for enemy submarines during World War II allowed scientists to piece together bathymetric maps of the seafloor. Multi-beam sounders work on research vessels today.
- These maps revealed amazing features like mid—ocean ridges, deep sea trenches, and abyssal plains.

Explore More

Use this resource to answer the questions that follow.

https://www.youtube.com/watch?v=mMazvbbkWYk

1. What was the first way to chart the ocean floor?
2. What happened in the 1920s?
3. How do we have maps of most of the seafloor? How does this method work?
4. Does this give a direct bathymetry?
5. What needs to happen to get an accurate view of the bathymetry of the seafloor?

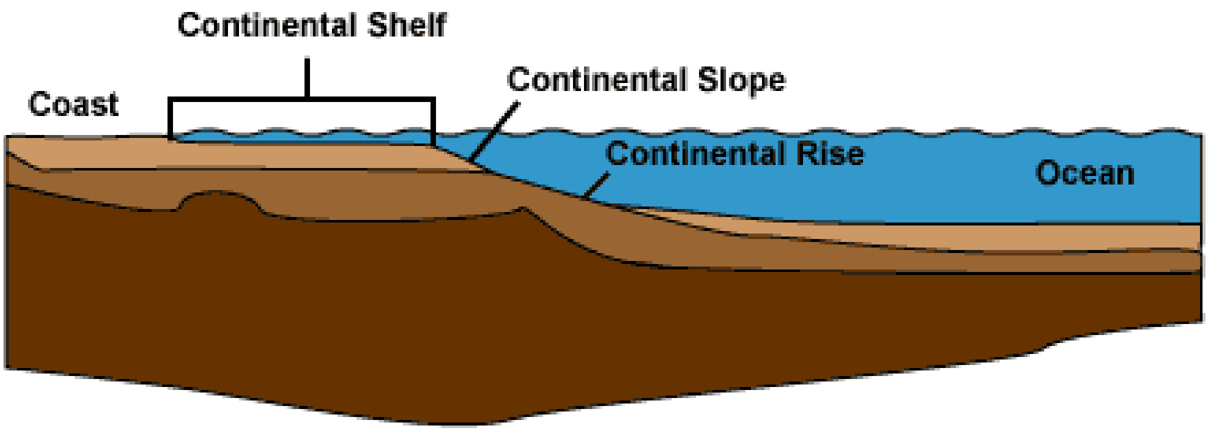


FIGURE 1.12
The continental margin is divided into the continental shelf, continental slope, and continental rise, based on the steepness of the slope.

Explore More Answers

1. Throw a lead line over the side and discover the depth.
2. Echo sounders were developed.
3. Modern satellite altimetry measures the elevation of the sea surface, which is affected by the shape of the seafloor.
4. No it is inferred.
5. The region needs to be surveyed with advanced echo sounding techniques.

Review

1. How does an echo sounder create a bathymetric map?
2. What are the important features located on the seafloor?
3. What do you think Alfred Wegener would have done with these bathymetric maps had he had access to them?

Review Answers

1. An echo sounder sends a sound wave out and when it bounces off something hard and comes back it is possible to calculate the time that journey took. This will tell the distance to that object, which can be used to create a map of the seafloor.
2. There are many: mid-ocean ridges, trenches, hotspot volcanic chains, abyssal plains, small volcanoes, and others.
3. Wegener would have used them to support his idea that the continents had once been joined and had drifted apart. We have to think that he would be very pleased!

1.5 Magnetic Evidence for Seafloor Spreading

- Explain how seafloor magnetism and the ages of seafloor rocks provide evidence of seafloor spreading.

What causes the strange stripes on the seafloor?

This pattern of stripes could represent what scientists see on the seafloor. Note that the stripes are symmetrical about the central dusky purple stripe. In the oceans, magnetic stripes are symmetrical about a mid-ocean ridge axis. What could cause this? What could it possibly mean?

Seafloor Magnetism

On our transit to the Mid-Atlantic ridge, we tow a magnetometer behind the ship. Shipboard magnetometers reveal the magnetic polarity of the rock beneath them. The practice of towing a magnetometer began during WWII when navy ships towed magnetometers to search for enemy submarines.

When scientists plotted the points of normal and reversed polarity on a seafloor map they made an astonishing discovery: the normal and reversed magnetic polarity of seafloor basalts creates a pattern.

- Stripes of normal polarity and reversed polarity alternate across the ocean bottom.

- Stripes form mirror images on either side of the mid-ocean ridges (**Figure** 1.13).
- Stripes end abruptly at the edges of continents, sometimes at a deep sea trench (**Figure** 1.14).

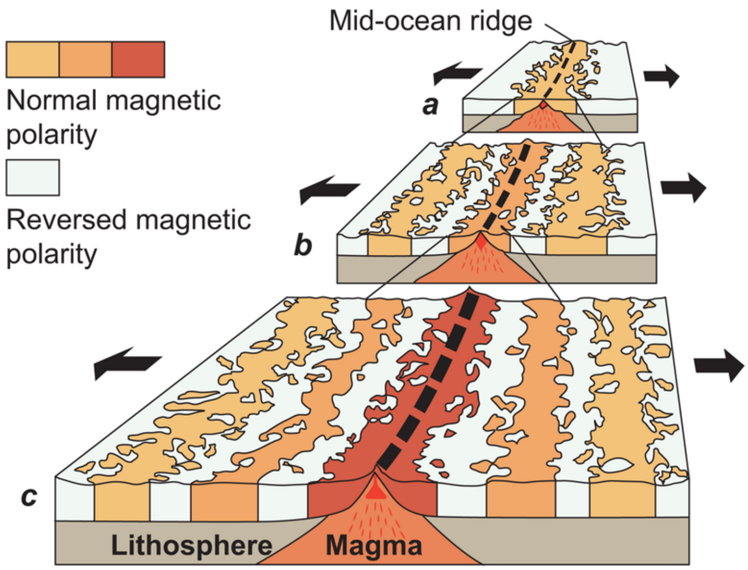


FIGURE 1.13
Magnetic polarity is normal at the ridge crest but reversed in symmetrical patterns away from the ridge center. This normal and reversed pattern continues across the seafloor.

The magnetic stripes are what created the **Figure** 1.13. Research cruises today tow magnetometers to add detail to existing magnetic polarity data.

Seafloor Age

By combining magnetic polarity data from rocks on land and on the seafloor with radiometric age dating and fossil ages, scientists came up with a time scale for the magnetic reversals. The first four magnetic periods are:

- Brunhes normal - present to 730,000 years ago.
- Matuyama reverse - 730,000 years ago to 2.48 million years ago.
- Gauss normal - 2.48 to 3.4 million years ago.
- Gilbert reverse –3.4 to 5.3 million years ago.

The scientists noticed that the rocks got older with distance from the mid-ocean ridges. The youngest rocks were located at the ridge crest and the oldest rocks were located the farthest away, abutting continents.

Scientists also noticed that the characteristics of the rocks and sediments changed with distance from the ridge axis as seen in the **Table** 1.1.

TABLE 1.1: **Characteristics of Crustal Rocks**

	Rock ages	Sediment thickness	Crust thickness	Heat flow
At ridge axis	youngest	none	thinnest	hottest
With distance from axis	becomes older	becomes thicker	becomes thicker	becomes cooler

Away from the ridge crest, sediment becomes older and thicker, and the seafloor becomes thicker. Heat flow, which indicates the warmth of a region, is highest at the ridge crest.

A map of sediment thickness is found here: http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_sedimentthickness.html .

The oldest seafloor is near the edges of continents or deep sea trenches and is less than 180 million years old (**Figure** 1.14). Since the oldest ocean crust is so much younger than the oldest continental crust, scientists realized that something was happening to the older seafloor.

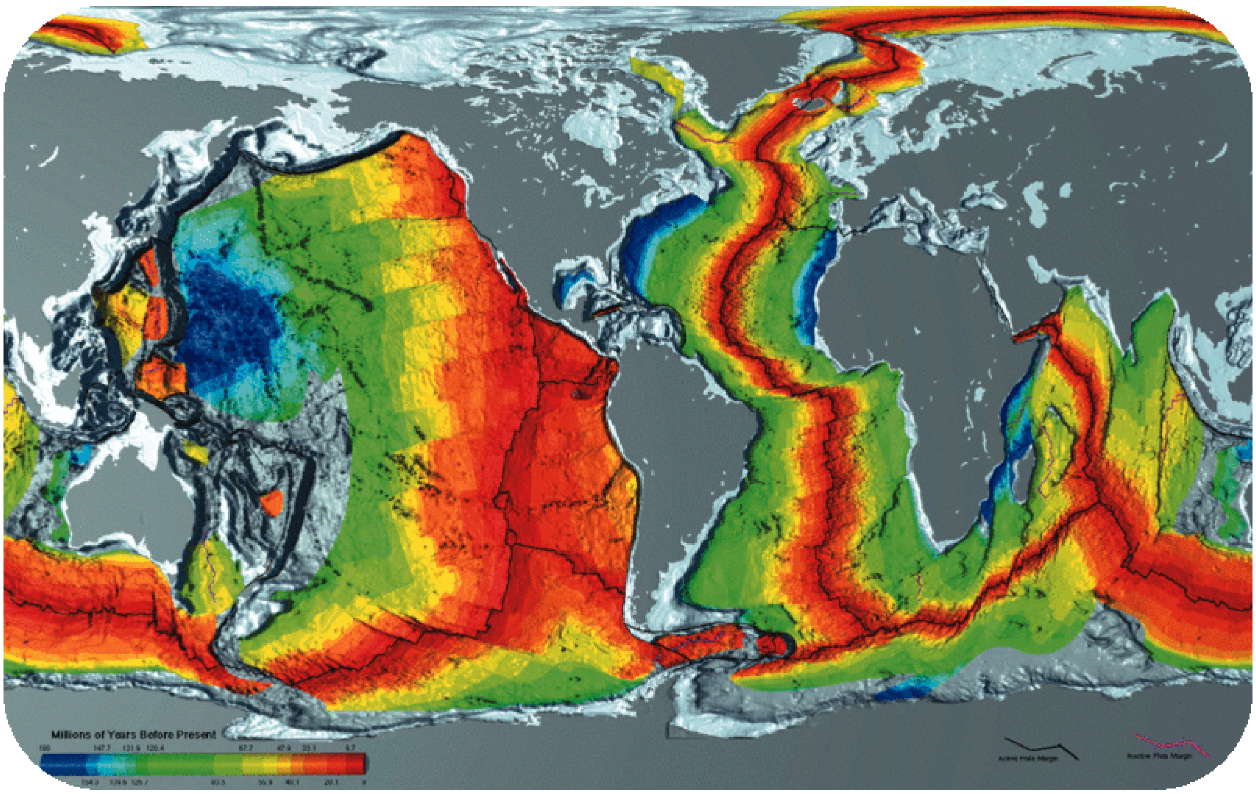


FIGURE 1.14

Seafloor is youngest at the mid-ocean ridges and becomes progressively older with distance from the ridge.

How can you explain the observations that scientists have made in the oceans? Why is rock younger at the ridge and oldest at the farthest points from the ridge? The scientists suggested that seafloor was being created at the ridge. Since the planet is not getting larger, they suggested that it is destroyed in a relatively short amount of geologic time.

This 65 minute video explains "The Role of Paleomagnetism in the Evolution of Plate Tectonic Theory": http://online.wr.usgs.gov/calendar/2004/jul04.html .

Summary

- Data from magnetometers dragged behind ships looking for enemy submarines in WWII discovered amazing magnetic patterns on the seafloor.
- Rocks of normal and reversed polarity are found in stripes symmetrically about the mid-ocean ridge axis.

- The age of seafloor rocks increases from the ridge crest to rocks the farthest from the ridges. Still, the rocks of the ocean basins are much younger than most of the rocks of the continents.

Explore More

Use the resource below to answer the questions that follow.

- **Plate tectonics: Evidence of plate movement** at

1. What is the most obvious piece of evidence that the plates were once joined together? Does this mean without doubt that they were once joined together? Why or why not?
2. What is in the middle of the Atlantic Ocean?
3. What does a cooling basalt do with respect to the magnetic field?
4. What pattern of magnetic minerals would you expect in basalt rock if the magnetic field never changed?
5. How does the magnetic orientation of minerals in basalts older than around 780,000 years differ from those that are younger than that age?
6. What happens to magnetic orientation in rocks in a sequence?
7. How are rocks right at the Mid-Atlantic Ridge oriented magnetically? How about rocks just out from those?
8. What pattern in magnetic orientation is seen across the seafloor?
9. What do scientists say about rocks that point in the opposite direction to the current magnetic field and are the same distance from the ridge?

Explore More Answers

1. The fit of the continents may mean they were joined but may be a coincidence.
2. A mountain range or ridge with underwater volcanic activity.
3. The magnetic minerals line up with the magnetic pole. When it is cool the magnetic minerals are frozen into place.
4. The minerals would point in the same direction no matter their age.
5. It is aligned the way it is today if it’s younger and in the opposite direction if it’s older.
6. The magnetic orientation goes normal to opposite.
7. The rocks at the ridge point in the direction of the current field but the ones further out go the opposite direction.
8. Positive and negative in stripes across the seafloor.
9. The rocks were formed at the ridge and moved away from each other.

Review

1. Describe the pattern the magnetic stripes make in the ocean floor.
2. How does magnetic polarity reveal the age of a piece of seafloor?
3. What other indications do scientists have regarding the age of the seafloor in various locations?

Explore More Answers

1. The ridge has rocks with normal polarity and outward from that on both sides the rocks have reverse polarity. These stripes continue across the seafloor, normal and reverse.
2. Since basalt can be dated, it is possible to know the years that a certain magnetic polarity occurred and so then the magnetic polarity can reveal the age of a rock.
3. Seafloor gets thicker with distance from the ridge and the thickness of sediment is greater.

1.6 Seafloor Spreading Hypothesis

- Define the seafloor spreading hypothesis and describe how seafloor spreading works.

"I shall consider this paper an essay in geopoetry..."

"...In order not to travel any further into the realm of fantasy than is absolutely necessary I shall hold as closely as possibly to a uniformitarian approach. . . " - Harry Hammond Hess, "History of Ocean Basins," 1962

It all came together in the early 1960s. A number of scientists put the evidence together and concluded that mantle convection drove a process they called seafloor spreading. New seafloor was continually being created at mid-ocean ridges. Old seafloor was being destroyed at deep-sea trenches. This was the mechanism that drove continental drift.

An Essay in Geopoetry

Harry Hess was a geology professor and a naval officer who commanded an attack transport ship during WWII. Like other ships, Hess's ship had echo sounders that mapped the seafloor. Hess discovered hundreds of flat-topped mountains in the Pacific that he gave the name **guyot**. He puzzled at what could have formed mountains that appeared to be eroded at the top but were more than a mile beneath the sea surface. Hess also noticed trenches that were as much as 7 miles deep.

Meanwhile, other scientists like Bruce Heezen discovered the underwater mountain range they called the Great Global Rift. Although the rift was mostly in the deep sea, it occasionally came close to land. These scientists thought the rift was a set of breaks in Earth's crust. The final piece that was needed was the work of Vine and Matthews, who had discovered the bands of alternating magnetic polarity in the seafloor symmetrically about the rift.

Seafloor Spreading

The features of the seafloor and the patterns of magnetic polarity symmetrically about the mid-ocean ridges were the pieces that Hess needed. He resurrected Wegener's continental drift hypothesis and also the mantle convection idea of Holmes.

Hess wrote that hot magma rose up into the rift valley at the mid-ocean ridges. The lava oozed up and forced the existing seafloor away from the rift in opposite directions. Since magnetite crystals point in the direction of the magnetic north pole as the lava cools, the different stripes of magnetic polarity revealed the different ages of the seafloor. The seafloor at the ridge is from the Brunhes normal; beyond that is basalt from the Matuyama reverse; and beyond that from the Gauss normal. Hess called this idea **seafloor spreading**.

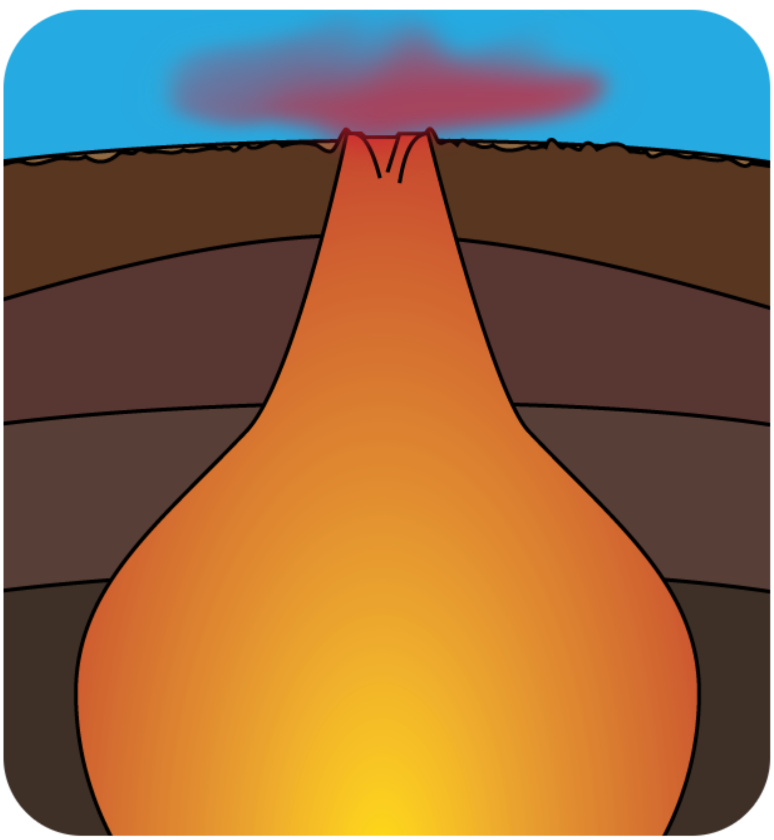


FIGURE 1.15
Magma at the mid-ocean ridge creates new seafloor.

These animations show the creation of magnetic stripes of normal and reversed polarity at a mid-ocean ridge: http://www.nature.nps.gov/GEOLOGY/usgsnps/animate/A49.gif and http://www.nature.nps.gov/GEOLOGY/usgsnps/animate/A55.gif .

Since new oceanic crust is created at the mid-ocean ridges, either Earth is getting bigger (which it is not) or oceanic crust must be destroyed somewhere. Since the oldest oceanic crust was found at the edges of the trenches, Hess hypothesized that the seafloor subducts into Earth's interior at the trenches to be recycled in the mantle.

- As oceanic crust forms and spreads, moving away from the ridge crest, it pushes the continent away from the ridge axis.
- If the oceanic crust reaches a deep sea trench, it sinks into the trench and is lost into the mantle.
- The oldest crust is coldest and lies deepest in the ocean because it is less buoyant than the hot new crust.

Hess could also use seafloor spreading to explain the flat topped guyots. He suggested that they were once active volcanoes that were exposed to erosion above sea level. As the seafloor they sat on moved away from the ridge, the crust on which they sat become less buoyant and the guyots moved deeper beneath sea level.

The Mechanism for Continental Drift

Seafloor spreading is the mechanism for Wegener's drifting continents. Convection currents within the mantle take the continents on a conveyor-belt ride of oceanic crust that, over millions of years, takes them around the planet's surface. The spreading plate takes along any continent that rides on it.

Seafloor spreading is the topic of this Discovery Education video: http://video.yahoo.com/watch/1595570/5390151 .

The history of the seafloor spreading hypothesis and the evidence that was collected to develop it are the subject of this video **(3a)**: http://www.youtube.com/watch?v=6CsTTmvX6mc (8:05).

MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/1445

Summary

- Seafloor spreading wedded together the mantle convection idea of Holmes, the continental drift idea of Wegener, new bathymetric and magnetic data from the seafloor, and made a coherent single idea.
- Harry Hess called his idea "an essay in geopoetry," possibly because so many ideas fit together so well, or more likely because at the time he didn't have all the seafloor data he needed for evidence.
- Seafloor spreading is the mechanism for the drifting continents.

Explore More

Use this resource to answer the questions that follow.

https://www.khanacademy.org/science/cosmology-and-astronomy/earth-history-topic/plate-techtonics/v/plates-moving-due-to-convection-in-mantle

1. What happens to water in a pot if you heat one side of the bottom of the pot?
2. Where is convection taking place within Earth?
3. What is the relationships between a convection cell and seafloor features?
4. What does the convection cell do to the lithosphere over it?

Explore More Answers

1. The water that's over the flame gets warmer and it is less dense because the molecules have more kinetic energy. This less dense water rises and cooler water moves into that area to replace it. As the rising water gets further from the flame it cools and becomes more dense and so it sinks. This creates a convection cell.
2. In the asthenosphere, the viscous but not brittle part of the mantle.
3. Material that is hot is less dense and moves up, where it may cause a divergent rift. It moves sideways and cools and eventually sinks. It gets heated up again.
4. It pushes the lithosphere up where it is rising and pulls it down where it is sinking.

Review

1. How does the pattern of magnetic stripes give evidence for seafloor spreading?
2. How does the topography of the seafloor give evidence for seafloor spreading?
3. How does seafloor spreading fit into the idea that continents move about on Earth's surface?

Review Answers

1. The pattern of magnetic stripes reveals that new seafloor is found at the ridge and increasingly older seafloor is found with increasing distance from the ridge. This means that seafloor forms at the ridge and spreads outward.
2. The ridge is elevated because the magma chamber below it buoys it up. The seafloor becomes deeper as it moves across the ocean and then finally the deep-sea trenches reveal that seafloor plunges into the mantle.
3. Since ocean floor is being created and is pushing outward, if a continent sits on the same plate, it can be pushed by the seafloor. Seafloor spreading is the mechanism for drifting continents.

1.7 Earth's Tectonic Plates

- Describe tectonic plates and how they move.

"With such wisdom has nature ordered things in the economy of this world, that the destruction of one continent is not brought about without the renovation of the earth in the production of another." —James Hutton, *Theory of the Earth, with Proofs and Illustrations, Vol. 1*, 1795.

Hutton's quote predates plate tectonics theory by about one-and-a-half centuries, but it seems as if he was talking about divergent and convergent plate boundaries. The next step in understanding the development of plate tectonics theory is to learn what it is that moves around on Earth's surface. It's not really a continent; it's a plate. What is a plate?

What is a Plate?

What portion of Earth makes up the "plates" in plate tectonics? Again, the answer came about in part due to war. In this case, the Cold War.

During the 1950s and early 1960s, scientists set up seismograph networks to see if enemy nations were testing atomic bombs. These seismographs also recorded all of the earthquakes around the planet. The seismic records were used to locate an earthquake's **epicenter**, the point on Earth's surface directly above the place where the earthquake occurs.

Why is this relevant? It turns out that earthquake epicenters outline the plates. This is because earthquakes occur everywhere plates come into contact with each other.

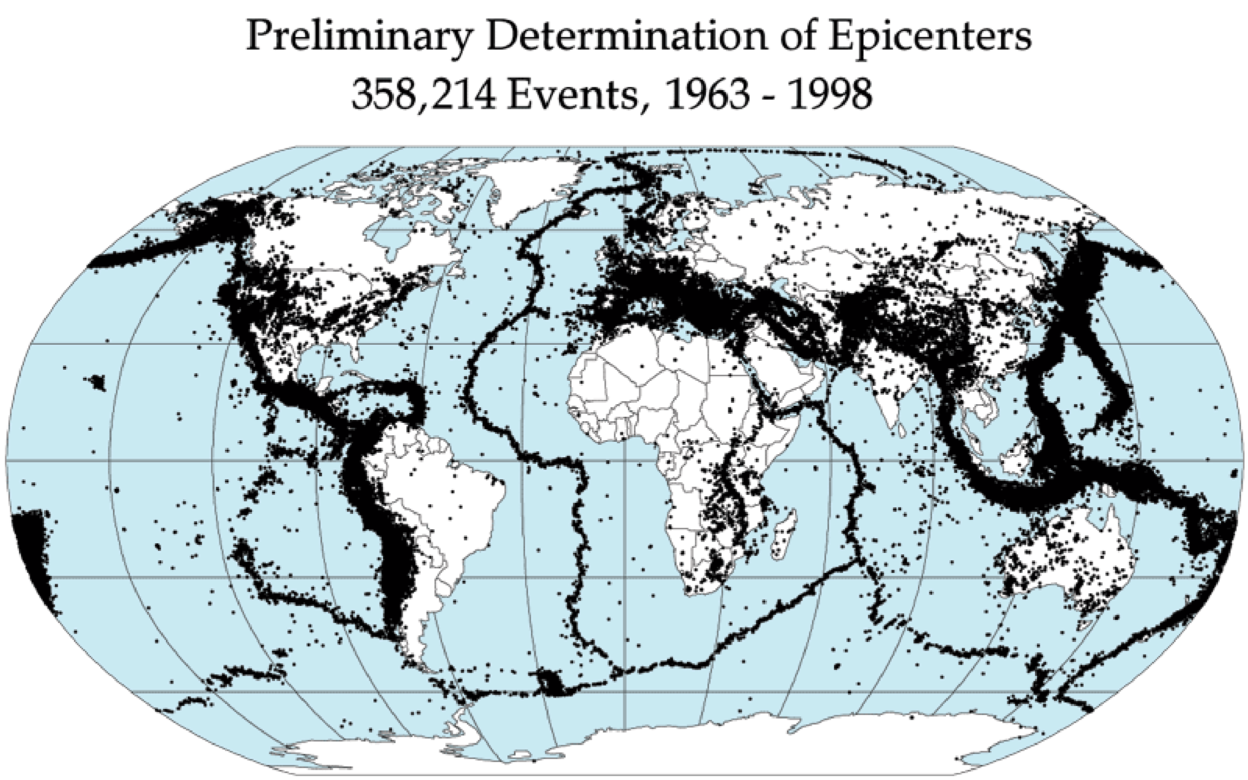


FIGURE 1.16
Earthquakes outline the plates.

The lithosphere is divided into a dozen major and several minor plates (**Figure** 1.16). A single plate can be made of all oceanic lithosphere or all continental lithosphere, but nearly all plates are made of a combination of both.

The movement of the plates over Earth's surface is termed **plate tectonics**. Plates move at a rate of a few centimeters a year, about the same rate fingernails grow.

How Plates Move

If seafloor spreading drives the plates, what drives seafloor spreading?

This goes back to Arthur Holmes' idea of mantle convection. Picture two convection cells side by side in the mantle, similar to the illustration in **Figure** 1.17.

1. Hot mantle from the two adjacent cells rises at the ridge axis, creating new ocean crust.
2. The top limb of the convection cell moves horizontally away from the ridge crest, as does the new seafloor.
3. The outer limbs of the convection cells plunge down into the deeper mantle, dragging oceanic crust as well. This takes place at the deep sea trenches.
4. The material sinks to the core and moves horizontally.
5. The material heats up and reaches the zone where it rises again.

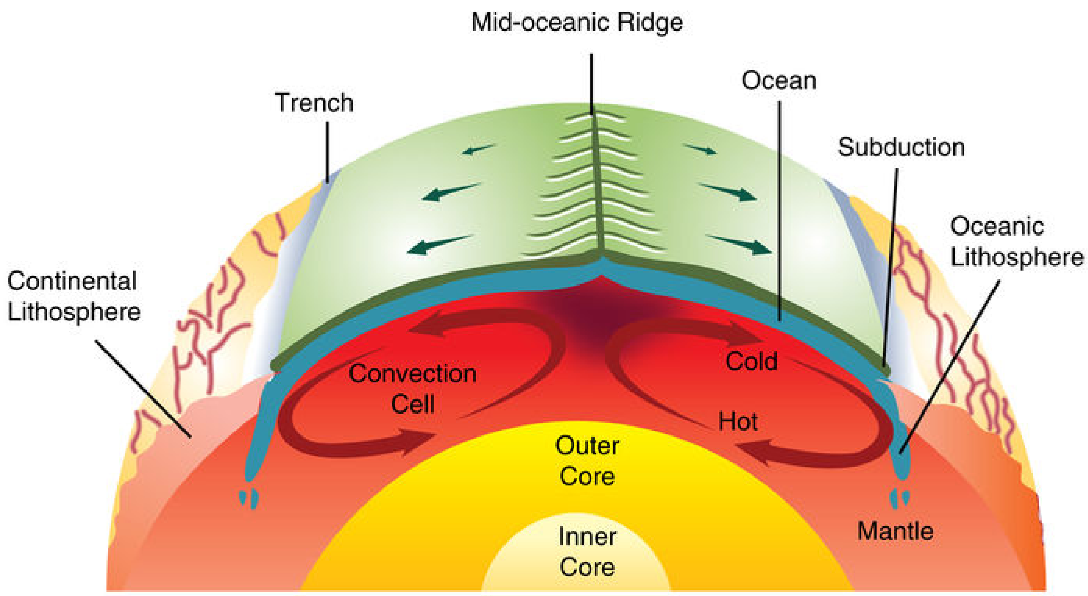


FIGURE 1.17
Mantle convection drives plate tectonics. Hot material rises at mid-ocean ridges and sinks at deep sea trenches, which keeps the plates moving along the Earth's surface.

Mantle convection is shown in these animations:

- http://www.youtube.com/watch?v=p0dWF_3PYh4
- http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_convection2.html

Plate Boundaries

Plate boundaries are the edges where two plates meet. How can two plates move relative to each other? Most geologic activities, including volcanoes, earthquakes, and mountain building, take place at plate boundaries. The features found at these plate boundaries are the mid-ocean ridges, trenches, and large transform faults (**Figure** 1.18).

- **Divergent plate boundaries**: the two plates move away from each other.
- **Convergent plate boundaries**: the two plates move towards each other.

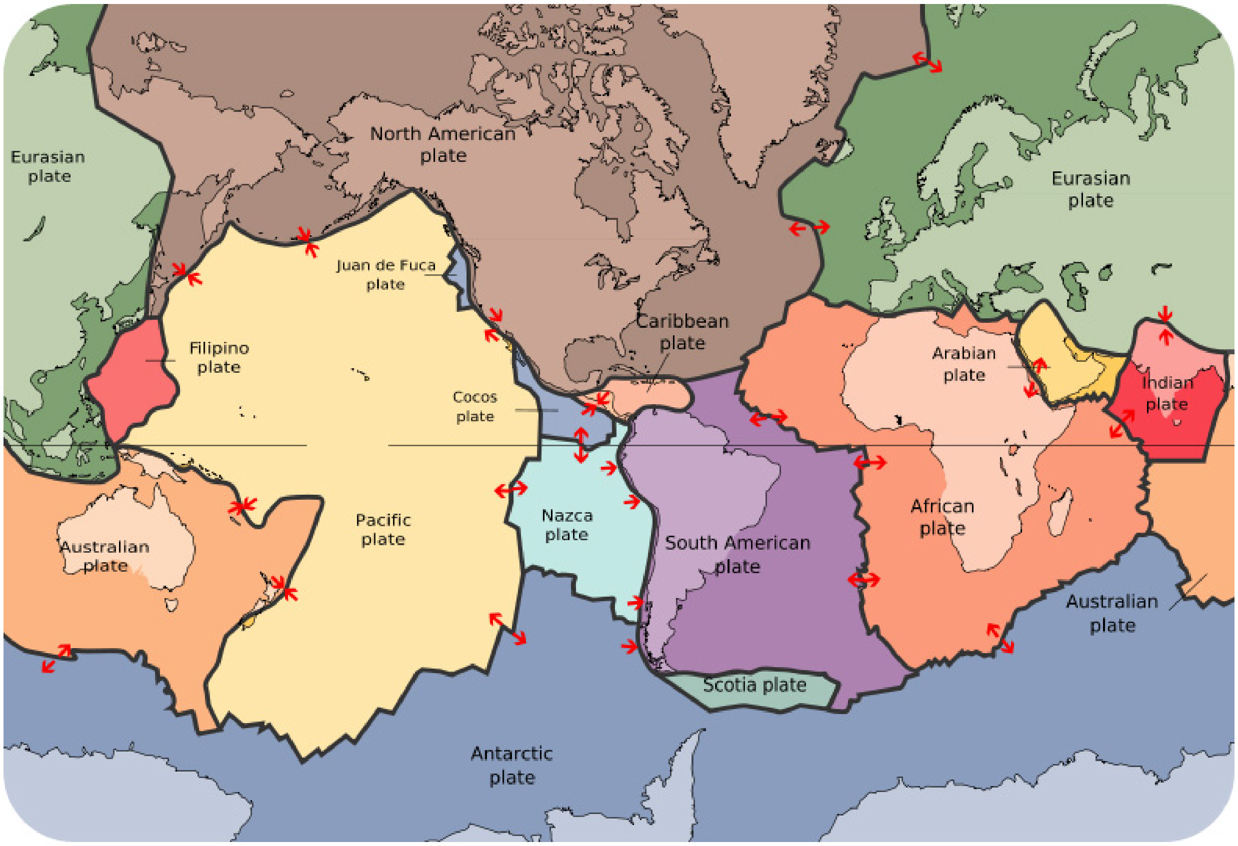


FIGURE 1.18
The lithospheric plates and their names. The arrows show whether the plates are moving apart, moving together, or sliding past each other.

- **Transform plate boundaries**: the two plates slip past each other.

The type of plate boundary and the type of crust found on each side of the boundary determines what sort of geologic activity will be found there. We can visit each of these types of plate boundaries on land or at sea.

Summary

- The plate in plate tectonics is a large chunk of lithosphere that can carry continental crust, oceanic crust, or some of each.
- Plates can be identified by the locations of earthquake epicenters. At the boundaries of plates are mid-ocean ridges, trenches, and large faults.
- Plates move by seafloor spreading, which is driven by mantle convection.
- Plates meet at plate boundaries. The three types are divergent, convergent, and transform.

Making Connections

MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/55145

Explore More

Use this resource to answer the questions that follow.

https://www.youtube.com/watch?v=1-HwPR_4mP4

1. How many types of plate boundaries are there? What are they?
2. Why didn't Wegener know about divergent plate boundaries?
3. What is happening at the Mid Atlantic Ridge?
4. What happens at a convergent plate boundary? What types of plates can meet up at convergent boundaries?
5. What happens at a transform boundary?
6. What three catastrophic effects can happen where plates move past each other?

Explore More Answers

1. There are three: divergent, convergent and transform.
2. They are mostly under the oceans.
3. Plates are being formed at the ridge and Africa and South America are being pushed apart.
4. The plates push into each other. Two oceanic or two continental plates or one of each can meet up.
5. The plates slide past each other.
6. Earthquakes, volcanism, tsunamis.

Review

1. How does the topography of the seafloor give evidence for seafloor spreading?
2. How does seafloor spreading fit into the idea that continents move about on Earth's surface?
3. How do convection cells drive the plates around Earth's surface?
4. What are the three types of plate boundaries?

Review Answers

1. The mid-ocean ridge is a continuous mountain rage that produces new oceanic crust. The trenches are where seafloor is consumed.
2. New seafloor is created at the ridges and pushes the older seafloor away. This makes the continents that are on those same plates move.
3. Rising mantle creates new seafloor at the ridge. The mantle then moves laterally and cools. It sinks when it becomes dense, dragging old seafloor into a trench.
4. convergent, divergent, transform

1.8 Divergent Plate Boundaries in the Oceans

- Describe the activity and features of divergent plate boundaries in the ocean and on land.

How could you walk between two plates?

On a bridge! Let's get off the Atlantis in Iceland. It's good to feel solid ground beneath our feet again! While in Iceland we'll take a walk on Leif the Lucky Bridge. Why did we sail across the ocean for this? Iceland is one place where a mid-ocean ridge is found above sea level.

Plate Divergence in the Ocean

Iceland provides us with a fabulous view of a mid-ocean ridge above sea level (**Figure** 1.19) As you can see, where plates diverge at a mid-ocean ridge is a rift valley that marks the boundary between the two plates. Basalt lava erupts into that rift valley and forms new seafloor. Seafloor on one side of the rift is part of one plate and seafloor on the other side is part of another plate.

Leif the Lucky Bridge straddles the divergent plate boundary. Look back at the photo at the top. You may think that the rock on the left side of the valley looks pretty much like the rock on the right side. That's true –it's all basalt and it even all has the same magnetic polarity. The rocks on both sides are extremely young. What's different is that the rock one side of the bridge is the youngest rock of the North American Plate while the rock on the other side is the youngest rock on the Eurasian plate.

This is a block diagram of a divergent plate boundary. Remember that most of these are on the seafloor and only in Iceland do we get such a good view of a divergent plate boundary in the ocean.

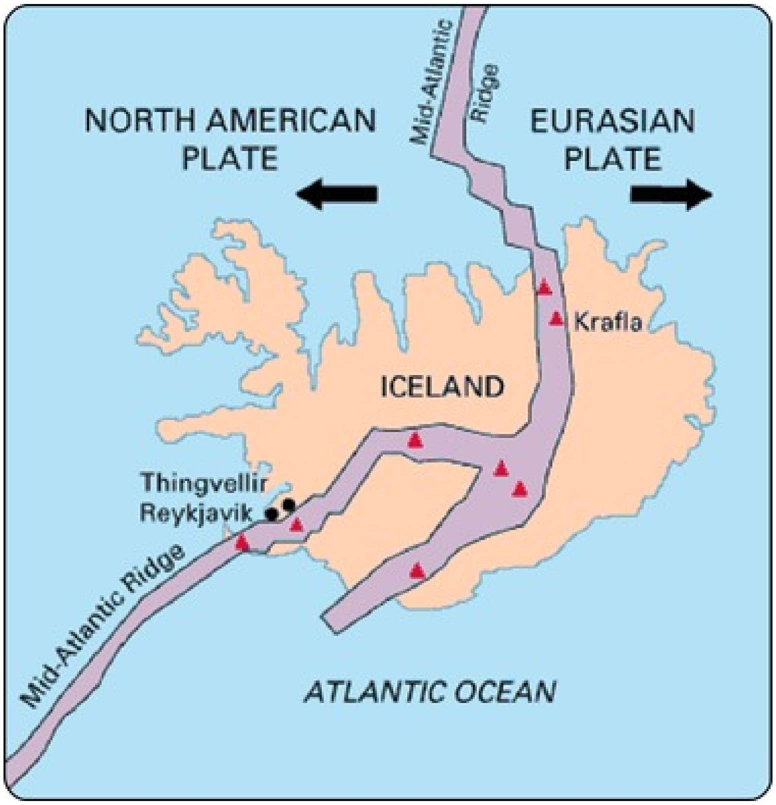


FIGURE 1.19

Iceland is the one location where the ridge is located on land: the Mid-Atlantic Ridge separates the North American and Eurasian plates

Convection Cells at Divergent Plate Boundaries

Remember that the mid-ocean ridge is where hot mantle material upwells in a convection cell. The upwelling mantle melts due to pressure release to form lava. Lava flows at the surface cool rapidly to become basalt, but deeper in the crust, magma cools more slowly to form gabbro. The entire ridge system is made up of igneous rock that is either extrusive or intrusive. The seafloor is also igneous rock with some sediment that has fallen onto it.

Earthquakes are common at mid-ocean ridges since the movement of magma and oceanic crust results in crustal shaking.

USGS animation of divergent plate boundary at mid-ocean ridge: http://earthquake.usgs.gov/learn/animations/animation.php?flash_title=Divergent+Boundary&flash_file=divergent&flash_width=500&flash_height=200 .

Divergent plate boundary animation: http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/11/AOTM_09_01_Divergent_480.mov .

Summary

- Oceanic plates diverge at mid-ocean ridges. New seafloor is created in the rift valley between the two plates.
- Lava cools to form basalt at the top of the seafloor. Deeper in the crust the magma cools more slowly to form gabbro.
- Iceland is a location where we can see a mid-ocean ridge above sea level.

Making Connections

MEDIA

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Explore More

Use this resource to answer the questions that follow.

https://www.khanacademy.org/science/cosmology-and-astronomy/earth-history-topic/plate-techtonics/v/plate-tectonics—geological-features-of-divergent-plate-boundaries

1. What happens at divergent plate boundaries?
2. What happens in the early stages of a divergent plate boundary?
3. The speaker makes a mistake at around 1:20 in the video. What is it?
4. Be aware that when the speaker is talking about hotspots he referring to places that are hot, not a hotspot like Hawaii. What happens to the material that is hot?
5. How does the hot material break through the lithosphere?
6. What forms first as the crust pulls apart? What is a famous example of this?
7. What is the Red Sea?
8. When the rift valley is submerged what is it called?
9. How does an ocean like the Atlantic form?

Explore More Answers

1. Plates are moving away from each other and new land is being created in the center.
2. There is solid crust on top of the solid lithosphere with the asthenosphere between.
3. He says that below the lithosphere the mantle is liquid. He is correct that it is super hot, but it is not all liquid.
4. It is less dense and so it moves upwards.
5. It causes it to be buoyant and dome upward so that it cracks.
6. It forms a rift valley. The East African Rift is an example.
7. It is an example of a rift valley that has water in it.
8. a mid-oceanic ridge
9. Hot material breaks up the crust and it gets pushed aside and opened until it becomes an ocean basin.

Review

1. What is the direction of plate motion at a divergent plate boundary?
2. Describe the relationship between the convection cell and volcanism at the mid-ocean ridge.
3. Why is the Leif the Lucky bridge so interesting?

Review Answers

1. The plates are both moving away from the boundary.
2. Volcanism takes place where hot mantle material is rising, in the upward moving portion of a convection cell.
3. The bridge straddles the Mid-Atlantic Ridge in Iceland.

1.9 Divergent Plate Boundaries

- Describe the activity and features of divergent plate boundaries on land.

What can we see in Western North America?

When we got off the Atlantis in Iceland a new batch of scientists got on for a different scientific investigation. We're now going to fly to western North America to see a different set of plate tectonic features. Western North America has all three of the different types of plate boundaries and the features that are seen at them.

Tectonic Features of Western North America

We're on a new trip now. We will start in Mexico, in the region surrounding the Gulf of California, where a divergent plate boundary is rifting Baja California and mainland Mexico apart. Then we will move up into California, where plates on both sides of a transform boundary are sliding past each other. Finally we'll end up off of the Pacific Northwest, where a divergent plate boundary is very near a subduction zone just offshore.

In the **Figure** 1.20 a red bar where seafloor spreading is taking place. A long black line is a transform fault and a black line with hatch marks is a trench where subduction is taking place. Notice how one type of plate boundary transitions into another.

Plate Divergence on Land

A divergent plate boundary on land rips apart continents (**Figure** 1.21).

In **continental rifting**, magma rises beneath the continent, causing it to become thinner, break, and ultimately split apart. New ocean crust erupts in the void, ultimately creating an ocean between continents. On either side of the ocean are now two different lithospheric plates. This is how continents split apart.

These features are well displayed in the East African Rift, where rifting has begun, and in the Red Sea, where water is filling up the basin created by seafloor spreading. The Atlantic Ocean is the final stage, where rifting is now separating two plates of oceanic crust.

FIGURE 1.20
This map shows the three major plate boundaries in or near California.

Baja California

Baja California is a state in Mexico just south of California. In the **Figure** 1.22, Baja California is the long, skinny land mass on the left. You can see that the Pacific Ocean is growing in between Baja California and mainland Mexico. This body of water is called the Gulf of California or, more romantically, the Sea of Cortez. Baja is on the Pacific Plate and the rest of Mexico is on the North American Plate. Extension is causing the two plates to move apart and will eventually break Baja and the westernmost part of California off of North America. The Gulf of California will expand into a larger sea.

Rifting has caused volcanic activity on the Baja California peninsula as seen in the **Figure** 1.23.

Can you relate what is happening at this plate boundary to what happened when Pangaea broke apart?

Summary

- Where continental rifting takes place, continents are split apart and an ocean may grow or be created between the two new plates.
- Baja California is rifting apart from mainland Mexico.
- Continental rifting can create major ocean basins, like the Atlantic.

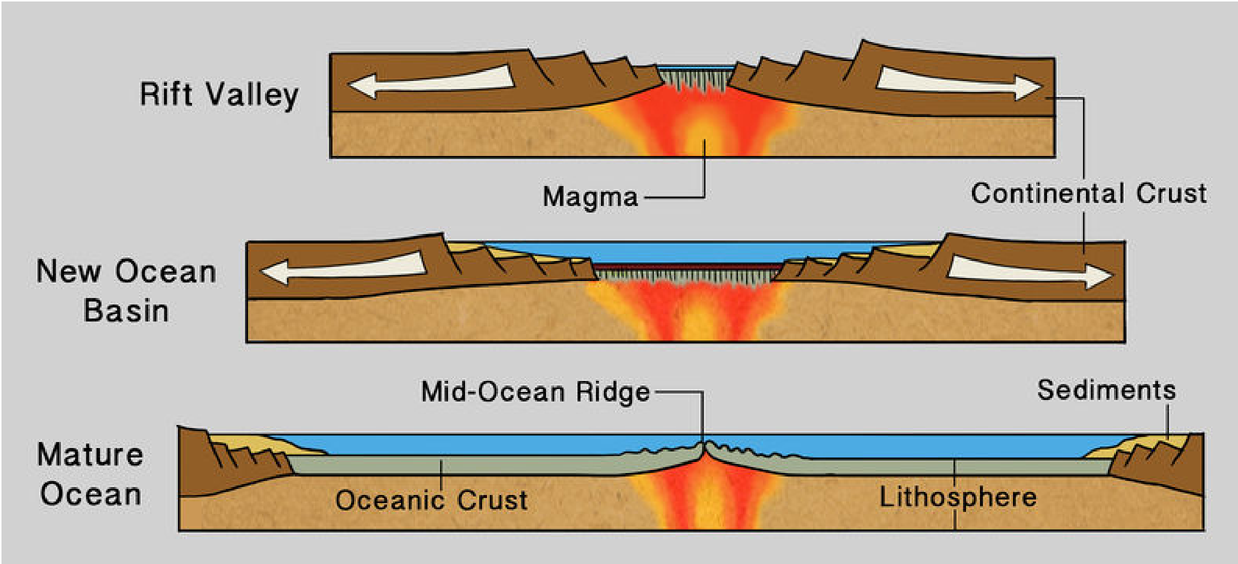


FIGURE 1.21
When plate divergence occurs on land, the continental crust rifts, or splits. This effectively creates a new ocean basin as the pieces of the continent move apart.

Making Connections

MEDIA
Click image to the left for use the URL below.
URL: http://gamma.ck12.org/flx/render/embeddedobject/55492

Explore More

Use this resource to answer the questions that follow.

http://www.cotf.edu/ete/modules/msese/earthsysflr/plates3.html

1. What are divergent boundaries?
2. Which layer is pulled apart?
3. What occurs along the faults on land?
4. What results when the magma reaches the surface?
5. List examples of rift valleys on land.

Explore More Answers

1. Places where plates are coming apart.

FIGURE 1.22
Baja California is rifting apart from mainland Mexico, as seen in this satellite image.

2. The lithosphere, the brittle surface layer, is pulled apart.
3. The plate breaks along parallel faults and blocks between the faults crack and drop down into the asthenosphere.
4. Magma seeps into the cracks and forms new land.
5. East African Rift, Kenya and Ethiopia; Rio Grand rift, New Mexico

Review

1. How is a divergent plate boundary on land different from one in the ocean?
2. What is happening to the Baja California peninsula?
3. How did continental rifting play into the breakup of Pangaea?

Review Answers

1. A divergent plate boundary on land rips continents apart and will create an ocean eventually. One in the ocean is further along in the process.
2. Baja California is rifting away from Mexico at a divergent plate boundary.
3. Pangaea broke into the continents we see today (more or less) as the continent rifted apart.

FIGURE 1.23
Volcanism in Baja California is evidence of rifting.

1.10 Transform Plate Boundaries

- Describe the activity and features of transform plate boundaries on land and in the ocean.

What could cause such an enormous scar on the land?

A transform plate boundary! As we continue up the West Coast, we move from a divergent plate boundary to a transform plate boundary. As in Iceland, where we could walk across a short bridge connecting two continental plates, we could walk from the Pacific Plate to the North American plate across this transform plate boundary. In this image, the San Andreas Fault across central California is the gash that indicates the plate boundary.

Transform Plate Boundaries

With transform plate boundaries, the two slabs of lithosphere are sliding past each other in opposite directions. The boundary between the two plates is a **transform fault**.

Transform Faults On Land

Transform faults on continents separate two massive plates of lithosphere. As they slide past each other, they may have massive earthquakes.

The San Andreas Fault in California is perhaps the world's most famous transform fault. Land on the west side is moving northward relative to land on the east side. This means that Los Angeles is moving northward relative to Palm Springs. The San Andreas Fault is famous because it is the site of many earthquakes, large and small. (**Figure** 1.24).

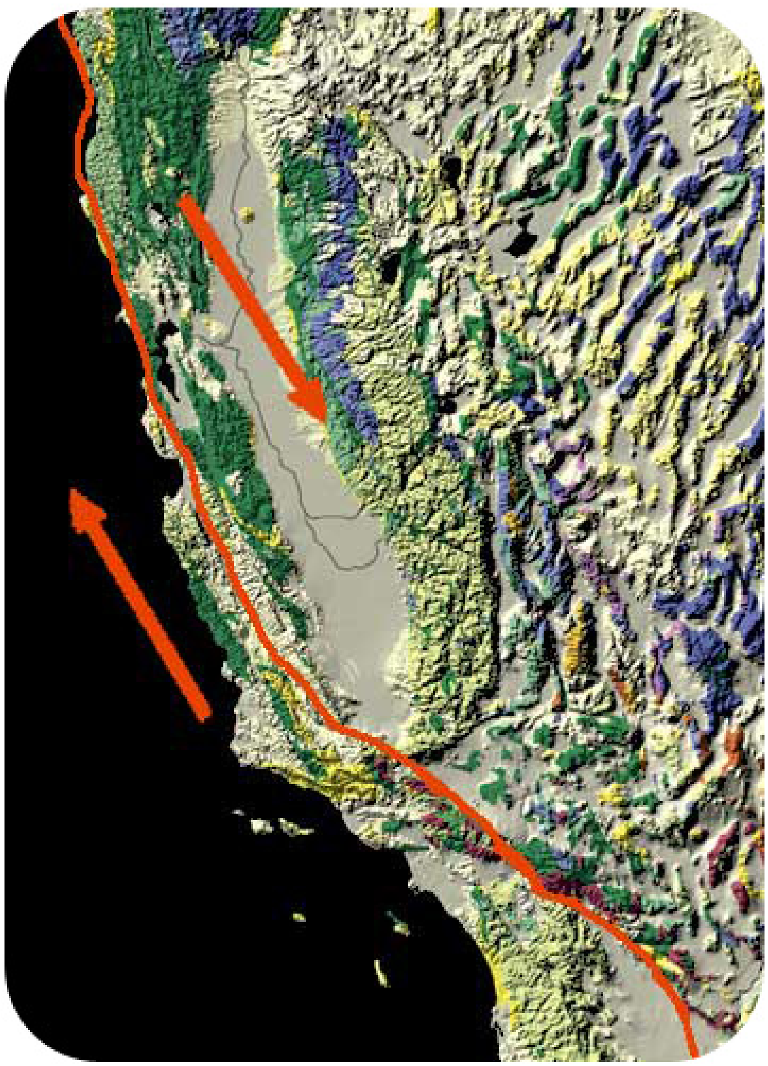


FIGURE 1.24

At the San Andreas Fault in California, the Pacific Plate is sliding northeast relative to the North American plate, which is moving southwest. At the northern end of the picture, the transform boundary turns into a subduction zone.

Transform plate boundaries are also found in the oceans. They divide mid-ocean ridges into segments. In the diagram of western North America, the mid-ocean ridge up at the top, labeled the Juan de Fuca Ridge, is broken apart by a transform fault in the oceans. A careful look will show that different plates are found on each side of the ridge: the Juan de Fuca plate on the east side and the Pacific Plate on the west side.

Summary

- A transform plate boundary divides two plates that are moving in opposite direction from each other.
- On land, transform faults are the site of massive earthquakes because they are where large slabs of lithosphere slide past each other.
- Transform faults in the oceans break mid-ocean ridges into segments.

Making Connections

MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/59085

Explore More

Use the resource below to answer the questions that follow.

- **Transform Plate Boundaries** at

http://www.learner.org/interactives/dynamicearth/slip3.html

1. Describe the motion of transform plate boundaries.
2. What is a fault?
3. What do transform plate boundaries produce?
4. Explain a strike-slip fault.
5. What is the best studied fault?
6. What two plates make this boundary?
7. Which direction are each of these plates moving?

Explore More Answers

1. Plates move past each other.
2. Where rock on both sides has been displaced relative to each other.
3. earthquakes
4. Strike slip faults have no vertical motion; the plates move horizontally and grind past each other.
5. San Andreas Fault
6. North America and Pacific
7. northwest and southeast

Review

1. What is the direction of plate motion at a transform plate boundary?
2. Why are transform faults on continents prone to massive earthquakes?
3. How do transform faults in the oceans compare with those on land?

Review Answers

1. The plates move laterally past each other in opposite directions.
2. The plates are large and the movement isn't smooth. The plates get stuck and only come apart when the energy has built up so much that there's a massive earthquake.
3. Oceanic crust is relatively thin and the faults break the mid-ocean ridges into segments but do not cause large earthquakes.

1.11 Ocean-Continent Convergent Plate Boundaries

- Describe the activity and features of convergent plate boundaries where an oceanic plate meets a continental plate.

What do you see at an ocean-continent convergent boundary?

We continue our field trip up the West Coast. Just offshore from Washington, Oregon, and Northern California is a subduction zone, where the Juan de Fuca Plate is sinking into the mantle. The Juan de Fuca Plate is being created at a spreading center, the Juan de Fuca Ridge. Let's see the results of subduction of the Juan de Fuca Plate.

Convergent Plate Boundaries

When two plates converge, what happens depends on the types of lithosphere that meet. The three possibilities are oceanic crust to oceanic crust, oceanic crust to continental crust, or continental crust to continental crust. If at least one of the slabs of lithosphere is oceanic, that oceanic plate will plunge into the trench and back into the mantle. The meeting of two enormous slabs of lithosphere and subduction of one results in magma generation and earthquakes. If both plates meet with continental crust, there will be mountain building. Each of the three possibilities is discussed in a different concept.

In this concept we look at subduction of an oceanic plate beneath a continental plate in the Pacific Northwest.

Ocean-Continent Convergence

When oceanic crust converges with continental crust, the denser oceanic plate plunges beneath the continental plate. This process, called **subduction**, occurs at the oceanic trenches. The entire region is known as a **subduction zone**. Subduction zones have a lot of intense earthquakes and volcanic eruptions. The subducting plate causes melting in the mantle above the plate. The magma rises and erupts, creating volcanoes. These coastal volcanic mountains are found in a line above the subducting plate (**Figure** 1.25). The volcanoes are known as a **continental arc**.

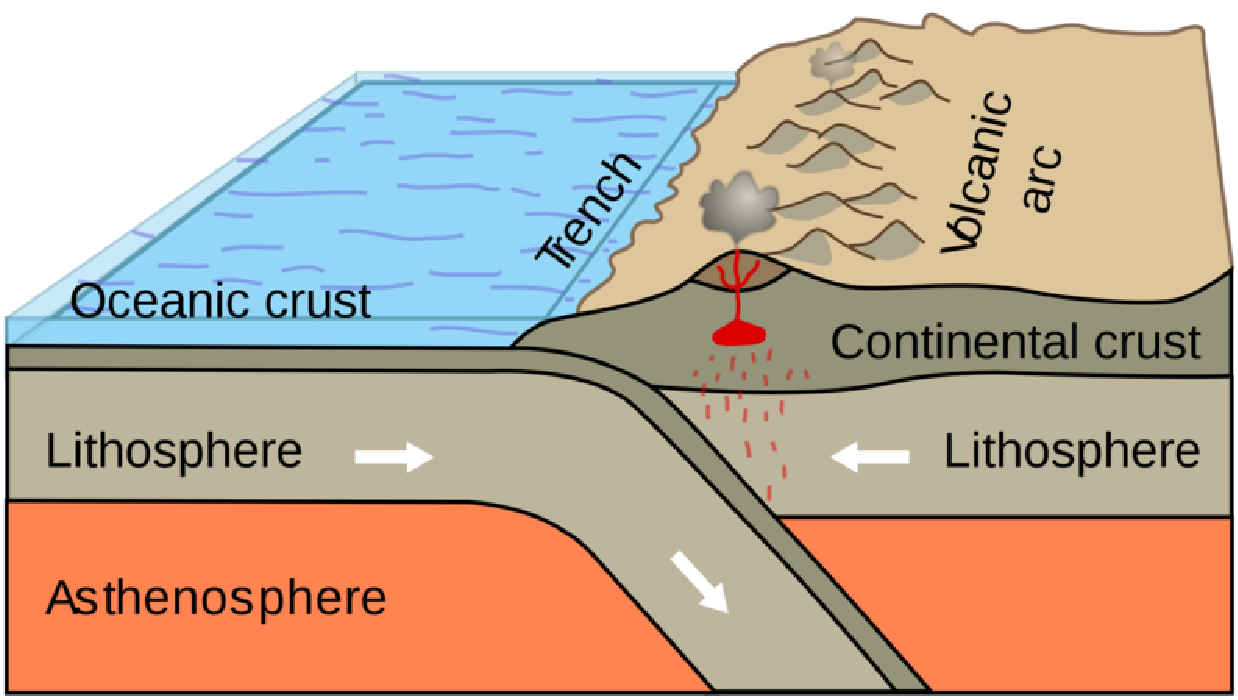


FIGURE 1.25

Subduction of an oceanic plate beneath a continental plate causes earthquakes and forms a line of volcanoes known as a continental arc.

The movement of crust and magma causes earthquakes. A map of earthquake epicenters at subduction zones is found here: http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_earthquakessubduction.html .

This animation shows the relationship between subduction of the lithosphere and creation of a volcanic arc: http://e arthguide.ucsd.edu/eoc/teachers/t_tectonics/p_subduction.html .

Remember that the mid-ocean ridge is where hot mantle material upwells in a convection cell. The upwelling mantle melts due to pressure release to form lava. Lava flows at the surface cool rapidly to become basalt, but deeper in the crust, magma cools more slowly to form gabbro. The entire ridge system is made up of igneous rock that is either extrusive or intrusive. The seafloor is also igneous rock with some sediment that has fallen onto it.

Cascades Volcanoes

The volcanoes of northeastern California —Lassen Peak, Mount Shasta, and Medicine Lake volcano —along with the rest of the Cascade Mountains of the Pacific Northwest, are the result of subduction of the Juan de Fuca plate beneath the North American plate (**Figure** 1.26). The Juan de Fuca plate is created by seafloor spreading just offshore at the Juan de Fuca ridge.

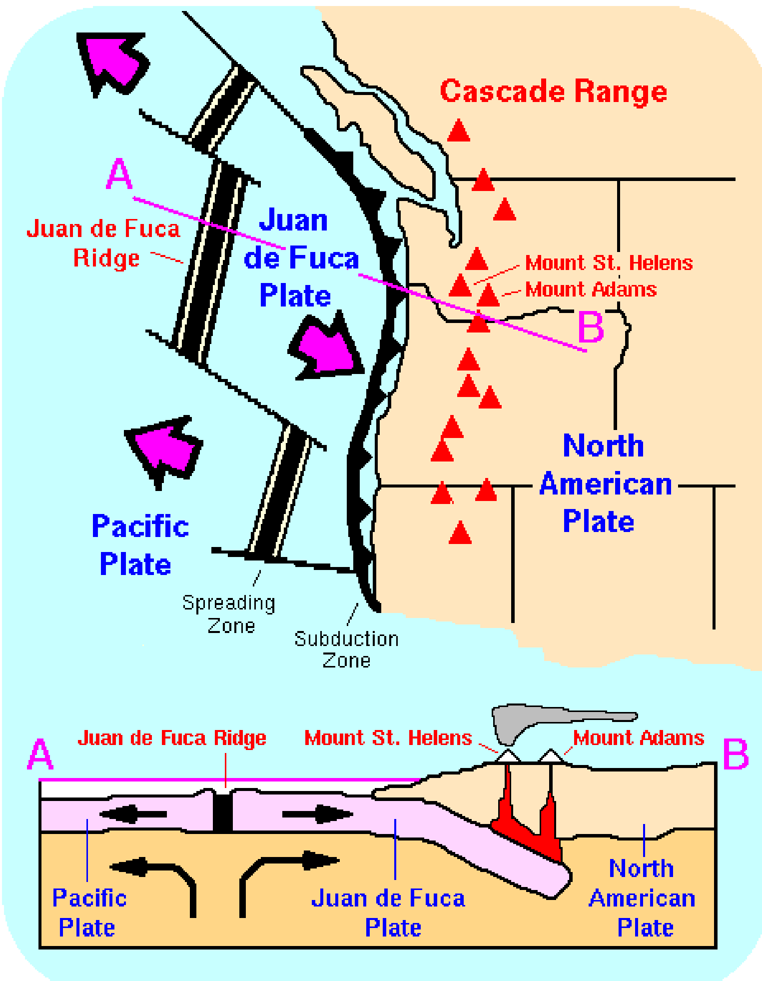


FIGURE 1.26
The Cascade Mountains of the Pacific Northwest are a continental arc.

Intrusions at a Convergent Boundary

If the magma at a continental arc is felsic, it may be too viscous (thick) to rise through the crust. The magma will cool slowly to form granite or granodiorite. These large bodies of intrusive igneous rocks are called **batholiths**, which may someday be uplifted to form a mountain range. California has an ancient set of batholiths that make up the Sierra Nevada mountains (**Figure** 1.27).

FIGURE 1.27
The Sierra Nevada batholith cooled beneath a volcanic arc roughly 200 million years ago. The rock is well exposed here at Mount Whitney. Similar batholiths are likely forming beneath the Andes and Cascades today.

An animation of an ocean continent plate boundary is seen here: http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/11/AOTM_09_01_Convergent_480.mov .

Summary

- When two plates come towards each other they create a convergent plate boundary.
- The plates can meet where both have oceanic crust or both have continental crust, or they can meet where one has oceanic and one has continental.
- Dense oceanic crust will subduct beneath continental crust or a less dense slab of oceanic crust.
- The oceanic plate subducts into a trench, resulting in earthquakes. Melting of mantle material creates volcanoes at the subduction zone.
- If the magma is too viscous to rise to the surface it will become stuck in the crust to create intrusive igneous rocks.

Making Connections

MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/59086

Explore More

Use these resources to answer the questions that follow.

https://www.khanacademy.org/science/cosmology-and-astronomy/earth-history-topic/plate-techtonics/v/plate-tectonics--geological-features-of-convergent-plate-boundaries

1. At what type of plate boundary to plates run into each other?
2. When one of the plates is oceanic, what happens?
3. What two things cause the mountain ranges that are the volcanic arc?
4. What is happening at a deep trench?
5. What happens when two continental plates run together?
6. What made Mt. Everest so high?

Explore More Answers

1. convergent
2. The oceanic plate is subducted beneath an oceanic plate or a continental plate.
3. The plate is buoying upward and the heat creates volcanoes.
4. One oceanic plate is being subducted under another; there are volcanoes that form underwater, which eventually form a group of islands.
5. The crustal portions keep jamming together; they keep pushing upwards creating mountain ranges.
6. The pushing together of the continental portions of the Indian and Eurasian plates.

Review

1. What is the direction of plate motion at a convergent plate boundary?
2. Describe the relationship between the convection cell and subduction at a trench.
3. Subduction is sometimes called crustal recycling. Why do you think this is the case?
4. What happens if magma is too viscous to rise through the crust to erupt at the surface?

Review Answers

1. The plates move toward each other.
2. The down-flowing side of a convection cell drags the subducting plate along with it.
3. Oceanic crust is pushed down into the mantle where it will mix with other mantle rocks. Eventually components of that crust will erupt at a mid-ocean ridge to become new oceanic crust.
4. It will remain below and cool to become an intrusive igneous rock.

1.12 Ocean-Ocean Convergent Plate Boundaries

- Learn the activity and features of convergent plate boundaries where one oceanic plate subducts beneath another oceanic plate.

What do you see in this satellite photo?

We continue our trip up western North America to find a convergent plate boundary where oceanic crust subducts beneath oceanic crust. North of the contiguous U.S. lies Canada, and north of Canada lies Alaska. A line of volcanoes, known as the Aleutian Islands, is the result of ocean-ocean convergence. In this satellite image is an erupting volcano, topped by snow or ice, and surrounded by seawater - a member of the Aleutian chain. Let's take a look at this boundary and the volcanic arc.

Convergent Plate Boundaries

When two plates converge, what happens depends on the types of lithosphere that meet. We explored what happens when oceanic crust meets continental crust. Another type of convergent plate boundary is found where two oceanic plates meet. In this case the older, denser slab of oceanic crust will plunge beneath the less dense one.

Ocean-Ocean

The features of a subduction zone where an oceanic plate subducts beneath another oceanic plate are the same as a continent-ocean subduction zone. An ocean trench marks the location where the plate is pushed down into the mantle. In this case, the line of volcanoes that grows on the upper oceanic plate is an **island arc**. Do you think earthquakes are common in these regions (**Figure** 1.28)?

In the north Pacific, the Pacific Plate is subducting beneath the North American Plate just as it was off of the coast of the Pacific Northwest. The difference is that here the North American plate is covered with oceanic crust. Remember

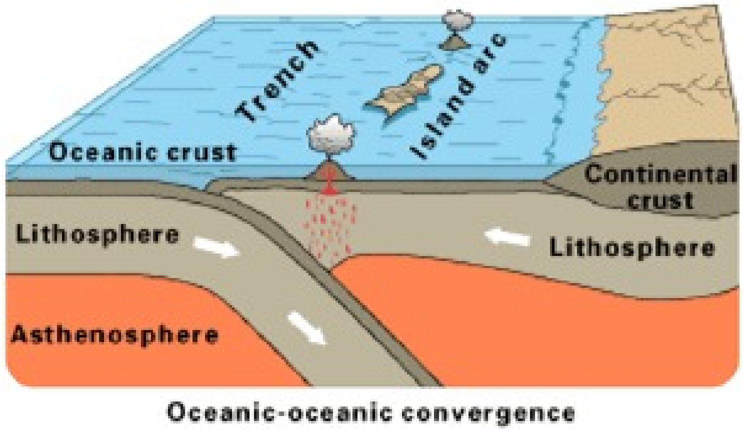


FIGURE 1.28
Subduction of an ocean plate beneath other oceanic crust results in a volcanic island arc, an ocean trench, and many earthquakes

that most plates are made of different types of crust. This subduction creates the Aleutian Islands, many of which are currently active (see **Figure** 1.29). Airplanes sometimes must avoid flying over these volcanoes for fear of being caught in an eruption.

Summary

- If the two plates that meet at a convergent plate boundary both are of oceanic crust, the older, denser plate will subduct beneath the less dense plate.
- The features of an ocean-ocean subduction zone are the same as those of an ocean-continent subduction zone, except that the volcanic arc will be a set of islands known as an island arc.
- The older plate subducts into a trench, resulting in earthquakes. Melting of mantle material creates volcanoes at the subduction zone.

Explore More

Use the resources below to answer the questions that follow.

- **Subduction Zones** at

http://www.nature.nps.gov/geology/usgsnps/pltec/converge.html

1. Describe a subduction zone.
2. What forms this subduction zone?
3. Where and why does melting occur?
4. What is formed on the continental plate?
5. Where can an example of this plate boundary be found?

- **Volcanic Arcs** at

http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_subduction.html

6. Why do arc volcanoes appear in a line?
7. Why are there volcanoes near subduction zones?

FIGURE 1.29
The arc of the island arc that is the Aleutian Islands is easily seen in this map of North Pacific air routes over the region.

Explore More Answers

1. At a subduction zone, the denser plate sinks beneath the less dense plate at a trench. Oceanic crust is destroyed.
2. A trench
3. At more than 100 km depth, the subducting plate loses fluids. This lowers the melting temperature of the overlying mantle and so that mantle melts.
4. volcanoes in an arc
5. the Cascades Mountains, the Andes
6. They rise above the subducting plate where it loses fluids.
7. The subducting plate initiates melting.

Review

1. Compare and contrast the features of an ocean-ocean convergent plate boundary with the features of an ocean-continent convergent plate boundary.
2. How do the Aleutian volcanoes differ from the Cascades volcanoes?
3. How do island arcs get their name?

Review Answers

1. Both have a volcanic arc, but in an ocean-ocean convergence zone the volcanoes are on an oceanic plate and in an ocean-continent convergence zone they are on the continental plate. Both have an oceanic trench where subduction takes place and there are many earthquakes.
2. The Aleutians are on an oceanic plate and so are the volcanoes are islands that make up an island arc; the Cascades are on a continental plate so the volcanoes stand on land.
3. The volcanoes rise from the seafloor so they are islands and the form of the chain is an arc shape.

1.13 Continent-Continent Convergent Plate Boundaries

- Describe the activity and features of convergent plate boundaries where two continental plates come together.

What do you see at a continent-continent convergent plate boundary?

Nowhere along the west coast of North America is there a convergent plate boundary of this type at this time. Why are there no continent-continent convergent boundaries in western North America? The best place to see two continental plates converging is in the Himalaya Mountains, the mountains that are the highest above sea level on Earth.

Continent-Continent Convergence

Continental plates are too buoyant to subduct. What happens to continental material when it collides? It has nowhere to go but up!

Continent-continent convergence creates some of the world's largest mountains ranges. Magma cannot penetrate this thick crust, so there are no volcanoes, although the magma stays in the crust. Metamorphic rocks are common because of the stress the continental crust experiences. With enormous slabs of crust smashing together, continent-continent collisions bring on numerous and large earthquakes.

A short animation of the Indian Plate colliding with the Eurasian Plate: http://www.scotese.com/indianim.htm .

An animation of the Himalayas rising: http://www.youtube.com/watch?v=ep2_axAA9Mw .

The Appalachian Mountains along the eastern United States are the remnants of a large mountain range that was created when North America rammed into Eurasia about 250 million years ago. This was part of the formation of Pangaea.

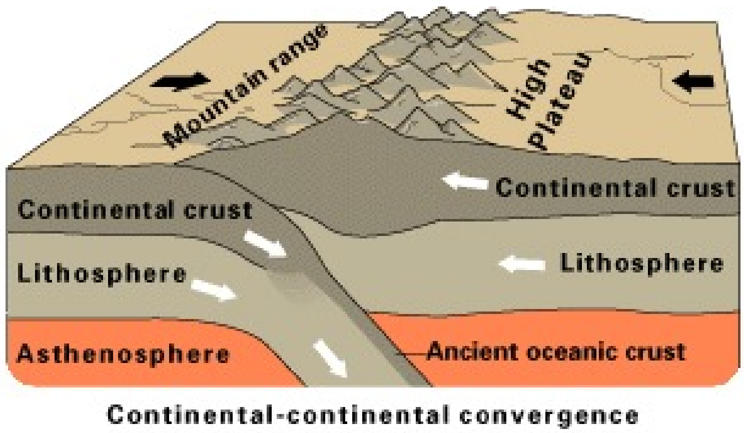


FIGURE 1.30
A diagram of two sections of continental crust converging.

Summary

- Continental crust is too buoyant to subduct. If the two plates that meet at a convergent plate boundary both consist of continental crust, they will smash together and push upwards to create mountains.
- Large slabs of lithosphere smashing together create large earthquakes.
- The activity at continent-continent convergences does not take place in the mantle, so there is no melting and therefore no volcanism.
- The amazing Himalaya Mountains are the result of this type of convergent plate boundary.
- Old mountain ranges, such as the Appalachian Mountains, resulted from ancient convergence when Pangaea came together.

Explore More

Use the resources below to answer the questions that follow.

- **Continent-Continent Convergence** at

http://www.nature.nps.gov/geology/usgsnps/pltec/converge.html

1. What happens when two continental plates converge?
2. What is the result of this convergence?

- **The Himalaya Mountains** at

http://pubs.usgs.gov/gip/dynamic/himalaya.html

3. Where are the Himalaya Mountains?
4. When were the Himalayas formed?
5. When did India ram into Asia?
6. How fast are the Himalayas rising?

Explore More Answers

1. The two continental plates are too buoyant to subduct so they collide.

2. They collide to create a large mountain range, like the Himalaya, the planet's tallest mountain range.
3. On the border between India and Tibet
4. 40 to 50 million years ago
5. at that time
6. about 9 meters per century

Review

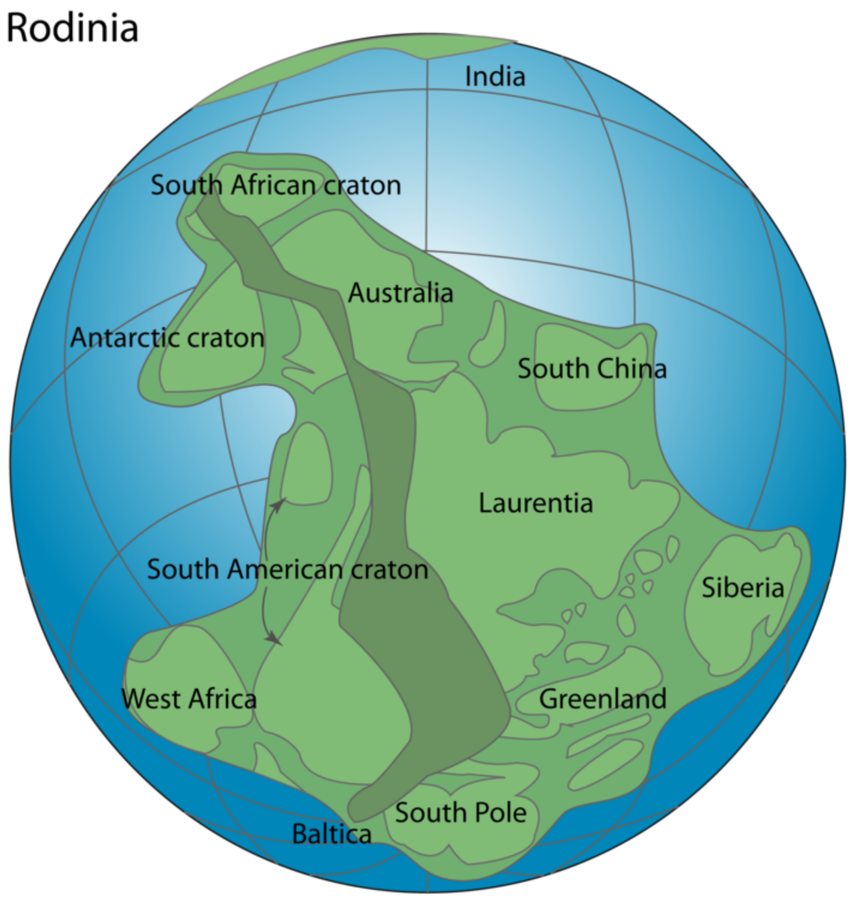
1. Compare and contrast the features of a continent-continent convergent plate boundary with the features of an ocean-continent convergent plate boundary.
2. What causes mountain ranges to rise in this type of plate boundary?
3. Why are there earthquakes but not volcanoes in this type of plate boundary?

Review Answers

1. Continent-continent convergence zones create the world's highest mountains. There are earthquakes but no volcanoes and metamorphic rocks are common. At continent-ocean convergence zones there are mountains, but they are volcanoes, and there are also earthquakes. Igneous volcanic rocks are common.
2. The crust can't subduct so it smashes together and crumples upward.
3. The crust is too thick for magma to penetrate.

1.14 Plate Tectonics through Earth History

- Explain the relationship between plate tectonics theory and the existence of supercontinents such as Pangaea.



That map is sort of familiar, but what is it?

Wegener's persistent search for evidence that the continents had been joined paid off. Scientists who came after him developed an understanding of seafloor spreading, which was the mechanism for Wegener's continental drift. Geologists know that Wegener was right because the movements of continents explain so much about the geological activity we see.

The existence of Wegener's supercontinent Pangaea is completely accepted by geologists today. But did it all begin with Pangaea? Or were there other supercontinents that came before?

Plate Tectonics Theory

First, let's review plate tectonics theory. Plate tectonics theory explains why:

- Earth's geography has changed over time and continues to change today.
- some places are prone to earthquakes while others are not.

- certain regions may have deadly, mild, or no volcanic eruptions.
- mountain ranges are located where they are.
- many ore deposits are located where they are.
- living and fossil species are found where they are.

Plate tectonic motions affect Earth's rock cycle, climate, and the evolution of life.

Supercontinent Cycle

Remember that Wegener used the similarity of the mountains on the west and east sides of the Atlantic as evidence for his continental drift hypothesis. Those mountains rose at the convergent plate boundaries where the continents were smashing together to create Pangaea. As Pangaea came together about 300 million years ago, the continents were separated by an ocean where the Atlantic is now. The proto-Atlantic ocean shrank as the Pacific Ocean grew.

The Appalachian mountains of eastern North America formed at a convergent plate boundary as Pangaea came together (**Figure** 1.31). About 200 million years ago, the they were probably as high as the Himalayas, but they have been weathered and eroded significantly since the breakup of Pangaea.

FIGURE 1.31
The Appalachian Mountains in New Hampshire.

Pangaea has been breaking apart since about 250 million years ago. Divergent plate boundaries formed within the continents to cause them to rift apart. The continents are still moving apart, since the Pacific is shrinking as the Atlantic is growing. If the continents continue in their current directions, they will come together to create a supercontinent on the other side of the planet in around 200 million years.

If you go back before Pangaea there were earlier supercontinents, such as Rodinia, which existed 750 million to 1.1 billion years ago, and Columbia, at 1.5 to 1.8 billion years ago. This **supercontinent cycle** is responsible for most of the geologic features that we see and many more that are long gone (**Figure** 1.32).

This animation shows the movement of continents over the past 600 million years, beginning with the breakup of Rodinia: http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_plate_reconstruction_blakey.html .

Summary

- Pangaea came together as a set of continent-continent convergent plate boundaries.
- Pangaea is still breaking up as the continents move apart. The Atlantic Ocean is getting bigger and the Pacific Ocean is getting smaller.

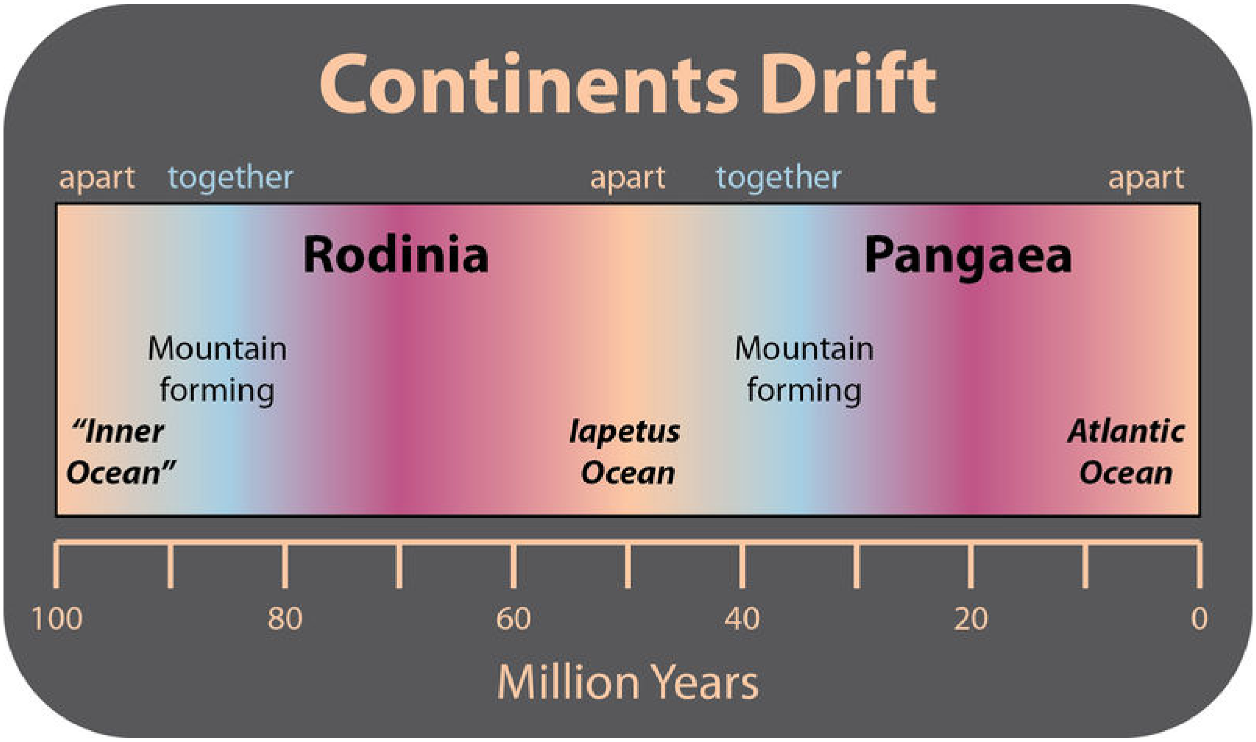


FIGURE 1.32
Scientists think that the creation and breakup of a supercontinent takes place about every 500 million years. The supercontinent before Pangaea was Rodinia. A new continent will form as the Pacific ocean disappears.

- Pangaea was not the first supercontinent and it won't be the last. The continents come together and break apart about every 500 million years in a process called the supercontinent (or Wilson) cycle.

Explore More

Use this resource to answer the questions that follow.

http://www.learner.org/interactives/dynamicearth/drift.html

1. What did Alfred Wegener notice?
2. What did he discover from his research?
3. What did he call the original supercontinent?
4. What happened 200 million years ago?
5. What landmasses split up 135 million years ago?
6. List the events that occurred 65 million years ago.
7. When did Greenland separate from North America?
8. Explain the plate tectonics theory.

Explore More Answers

1. Wegener noticed that the coastlines of Africa and South America could fit together.

2. He found evidence that the fossils and geologic formations on the two continents also matched.
3. Pangaea
4. Pangaea began to split apart.
5. Gondwana
6. Rifting in Laurasia so that North America and Eurasia separated. South America and Madagascar split from Africa.
7. 50 to 40 mya.
8. Earth's lithosphere is broken into plates that move around the planet. This movement explains the how and why of earthquakes, volcanoes and other geologic events.

Review

1. Describe the plate tectonics processes that brought Pangaea together.
2. Describe the plate tectonics processes that split Pangaea up.
3. Why do scientists think that there will be another supercontinent in the future?

Review Answers

1. Pangaea came together because convergent plate boundaries around the proto-Atlantic shrank the ocean basin and the continents came together.
2. Divergent plate boundaries split Pangaea up; first there was continental rifting and then the Atlantic Ocean basin formed.
3. The processes continue and the continents will smash together on the other side of the planet, unless they change direction.

1.15 Intraplate Activity

- Describe and explain volcanic activity that occurs within oceanic and continental plates.


What would you think if you heard that all geological activity does NOT take place at plate boundaries?

These photos of fabulous geological activity are going to rock your world. Why? After all of these concepts in which you learned that volcanoes and earthquakes are located around plate boundaries, this last concept in Plate Tectonics doesn't quite fit. These volcanoes are located away from plate boundaries. Two such locations are Hawaii and Yellowstone. Yellowstone is in the western U.S. and Hawaii is in the central Pacific.

Intraplate Activity

A small amount of geologic activity, known as **intraplate activity**, does not take place at plate boundaries but within a plate instead. Mantle plumes are pipes of hot rock that rise through the mantle. The release of pressure causes melting near the surface to form a **hotspot**. Eruptions at the hotspot create a volcano.

Hotspot volcanoes are found in a line (**Figure** 1.33). Can you figure out why? *Hint*: The youngest volcano sits above the hotspot and volcanoes become older with distance from the hotspot.

An animation of the creation of a hotspot chain is seen here: http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_hawaii.html .

Intraplate Activity in the Oceans

The first photo above is of a volcanic eruption in Hawaii. Hawaii is not in western North America, but is in the central Pacific ocean, near the middle of the Pacific Plate.

The Hawaiian Islands are a beautiful example of a hotspot chain in the Pacific Ocean. Kilauea volcano lies above the Hawaiian hotspot. Mauna Loa volcano is older than Kilauea and is still erupting, but at a slower rate. The islands get progressively older to the northwest because they are further from the hotspot. This is because the Pacific Plate is moving toward the northwest over the hotspot. Loihi, the youngest volcano, is still below the sea surface.

Since many hotspots are stationary in the mantle, geologists can use some hotspot chains to tell the direction and the speed a plate is moving (**Figure** 1.34). The Hawaiian chain continues into the Emperor Seamounts. The bend in the

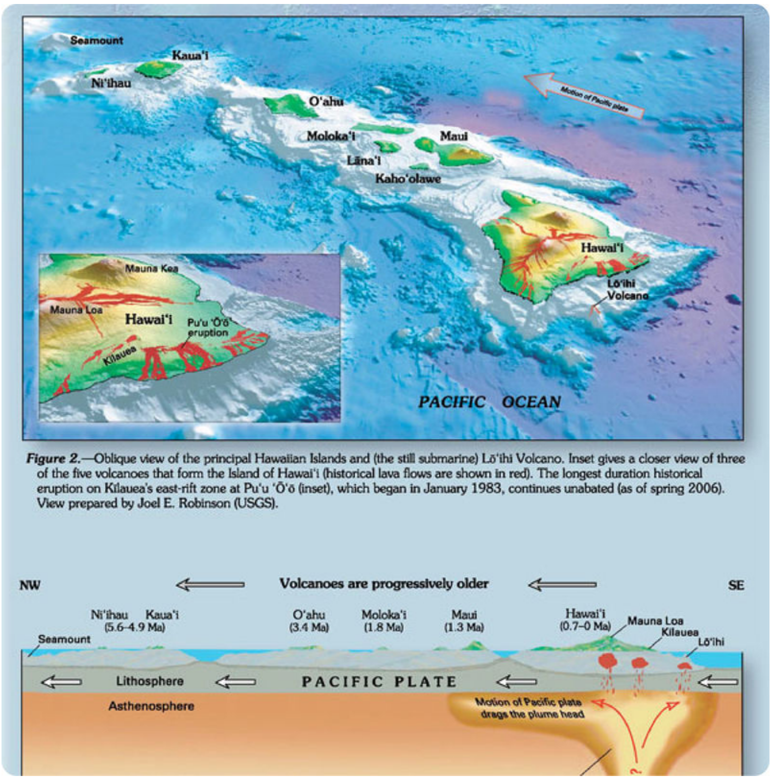


FIGURE 1.33
The Hawaiian Islands have formed from volcanic eruptions above the Hawaii hotspot.

chain was caused by a change in the direction of the Pacific Plate 43 million years ago. Using the age and distance of the bend, geologists can figure out the speed of the Pacific Plate over the hotspot.

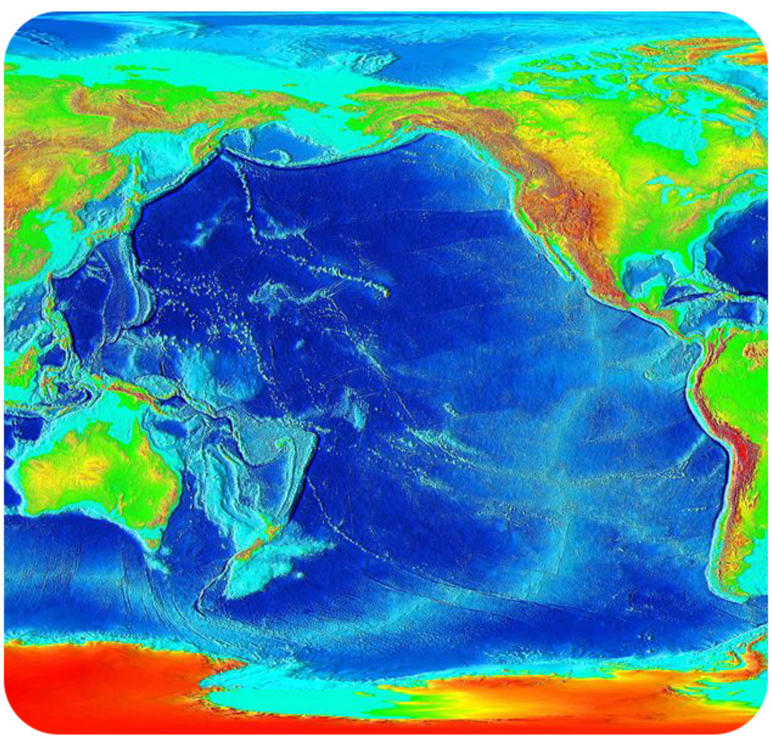


FIGURE 1.34
The Hawaiian-Emperor chain can be traced from Hawaii in the central Pacific north of the Equator into the Aleutian trench, where the oldest of the volcanoes is being subducted. It looks like a skewed "L".

Intraplate Activity on the Continents

The second photo in the introduction is of a geyser at Yellowstone National Park in Wyoming. Yellowstone is in the western U.S. but is inland from the plate boundaries offshore.

Hotspot magmas rarely penetrate through thick continental crust, so hotspot activity on continents is rare. One exception is the Yellowstone hotspot (**Figure** 1.35). Volcanic activity above the Yellowstone hotspot on can be traced from 15 million years ago to its present location on the North American Plate.

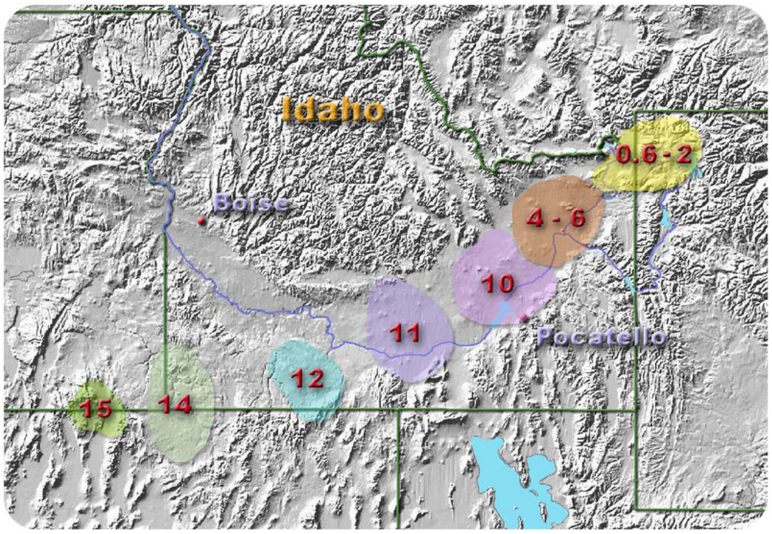


FIGURE 1.35
The ages of volcanic activity attributed to the Yellowstone hotspot.

Summary

- Not all geological activity is found at plate boundaries. Some volcanic activity, with accompanying earthquakes, is located within a plate. This is called intraplate activity.
- Intraplate activity occurs above mantle plumes that cause melting at a hotspot.
- Hotspots erupt mostly on oceanic crust. Hawaii is an example. A few hotspots, like Yellowstone, erupt on continental crust. The difference is due to the thickness of the crust.
- Hotspots can be used to tell the speed and direction that a plate is moving, since the hotspots are stationary within the mantle.

Explore More

Use these resources to answer the questions that follow.

http://www.youtube.com/watch?v=D1eibbfAEVk

MEDIA
Click image to the left for use the URL below.
URL: http://gamma.ck12.org/flx/render/embeddedobject/116519

1. Where are the Hawaiian islands located in relation to plate boundaries?
2. What are hotspots?
3. The speaker falsely says that plumes of material come from the upper core. If that were true what would the Hawaiian volcanoes be made of?
4. Why do mantle plumes not move?
5. What evidence supports the theory that hotspots are stationary?
6. Why is Kauai older than the big island?
7. How does a volcano form on a moving plate?
8. Why is the big island bigger than Kauai?

Explore More Answers

1. Hawaii is not near plate boundaries.
2. Hotspots are where the volcanic activity that creates the Hawaiian volcanoes come from. Hotspots may come from the mantle-core boundary.
3. iron and nickel metal
4. They are not connected to the convection cells in the mantle.
5. The plate moves over the hotspot so the ages of the Hawaiian islands support that the plume is stationary.
6. It was over the hotspot millions of years ago.
7. Lava erupts over time and builds up the volcano before it moves off the hotspot.
8. It is made of five volcanoes that are joined. Kauai has been eroding over time.

Review

1. What is a mantle plume and how is it related to a hotspot?
2. How do scientists use hotspot volcanism to tell the direction and speed of a plate?
3. Why are hotspot volcanoes much more common in the oceans than on continents?

Review Answers

1. Hotspots are where pressure release melting of a mantle plume melts rock.
2. Scientists determine the age of the rock and then use the distance from the hotspot and the shape of the hotspot volcanic chain to determine plate motions.
3. Hotspots do not penetrate the continental crust very well.

Summary

In the early 20th century, Alfred Wegener was the first persistent scientist to propose the idea that continents move around on Earth's surface. The meteorologist amassed a tremendous amount of evidence but could not think of a mechanism that others would accept to explain how solid continents could plow through ocean basins. Wegener's idea was abandoned. His continental drift idea was resurrected after World War II when scientists started to put together data about the seafloor. The astonishing features of the seafloor, the strange pattern of rock ages across the seafloor, and the history of the magnetic north pole on land, gave scientists in the early 1960s a great deal to mull over. From this work Harold Hess propose seafloor spreading as a mechanism for drifting continents. The resulting theory of plate tectonics is the explanation of what happens as plates of Earth's lithosphere interact at different types of plate boundaries.

1.16 References

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