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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 1.1). 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 1.1
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 1.2).

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.
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 is still breaking up as the continents move apart. The Atlantic Ocean is getting bigger and the Pacific Ocean is getting smaller.
- 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.

**Practice**

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.
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?

References

1. Rich Moffitt. CC BY 2.0
2. Jodi So. CC BY-NC 3.0
**Concept 2**

**Theory of Plate Tectonics**

- Explain the theory of plate tectonics theory.
- Describe how plate tectonics leads to existence of supercontinents such as Pangaea.

---

**What would Wegener think?**

Like any great theory, plate tectonics makes a tremendous amount of sense. The whole story fits together so perfectly. Wegener had so much evidence that the continents had once been joined. Seafloor spreading is a perfect mechanism for moving those continents. It’s really too bad that Alfred Wegener is not here to learn about the theory of plate tectonics. It seems certain that he would be ecstatic!

---

**Plate Tectonics Theory**

The theory of plate tectonics is what brings together continental drift and seafloor spreading. Plates are made of lithosphere topped with oceanic and/or continental crust. The plates are moved around on Earth’s surface by seafloor spreading. Convection in the mantle drives seafloor spreading. Oceanic crust is created at mid-ocean ridges. The crust moves outward from the ridge over time. The crust may eventually sink into the mantle and be destroyed. If a continent sits on a plate with a mid-ocean ridge, the continent will be pushed along.
Plate Boundaries

Two plates meet at a plate boundary. There are three types of plate boundaries since there are three ways that plates can meet. Plates can move away from each other. They can move toward each other. Finally, they can slide past each other. The three types of plate boundaries are divergent, convergent, and transform. They are described in the following three concepts.

Most geological activity takes place at plate boundaries. This activity includes volcanoes, earthquakes, and mountain building. The activity occurs as plates interact. Giant slabs of lithosphere moving around can create a lot of activity! The features seen at a plate boundary are determined by the direction of plate motion and by the type of crust found at the boundary.

What the Theory Explains

The theory of plate tectonics explains most of the features of Earth’s surface. It explains why earthquakes, volcanoes and mountain ranges are where they are. It explains where to find some mineral resources. Plate tectonics is the key that unlocks many of the mysteries of our amazing planet. 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 of plants and animals are found where they are.
- some continental margins have a lot of geological activity, and some have none.

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

Vocabulary

- plate boundary: Location at which two plates come together.

Summary

- The theory of plate tectonics brings together continental drift and seafloor spreading.
- At a plate boundary, two plates can be moving apart, together or past each other.
- Plate tectonics theory explains many things in geology, such as where volcanoes, earthquakes, mountain ranges, ore deposits, and other features are located.

Practice

Use the resource below to answer the questions that follow.

- Plate Tectonics at http://www.youtube.com/watch?v=nfziy_860GU (3:27)
1. Where is the Cascade Range found?
2. What does the Cascade Range include?
3. What formed the Cascade mountains?
4. What is a plate boundary?
5. List the three ways plates interact.
6. What is subduction?
7. What is the Ring of Fire?
8. What do colliding plates form?

**Review**

1. What is a plate boundary?
2. What three interactions can plates have? These are the three major types of plate boundaries.
3. In general, what does the theory of plate tectonics explain?
“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.

### Preliminary Determination of Epicenters

**358,214 Events, 1963 - 1998**

![Earthquakes outline the plates.](figure3_1.png)

The lithosphere is divided into a dozen major and several minor plates (**Figure 3.1**). 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 3.2**.

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.

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://www.youtube.com/watch?v=p0dWF_3PYh4)
- [http://earthguide.ucsd.edu/eoc/teachers/t_tectonics/p_convection2.html](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 3.3).

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

Use this resource to answer the questions that follow.

1. Which two plates meet in California?
2. What occurs where two plates meet?
3. What is an ocean ridge?
4. What is a strike-slip fault?
5. What occurs at strike-slip faults?
6. What evidence can be seen in California of the movement of the plates?

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?

References

1. Courtesy of NASA. . Public Domain
2. CK-12 Foundation. . CC BY-NC 3.0
What is tectonics?
Dividing the lithosphere into plates is one thing. Having the plates move around on the planet is another! A conveyor belt is a good analogy for how a plate moves. How the plates move and where they move is the "tectonics" part of plate tectonics.

Plate Motions
Scientists have determined the direction that each plate is moving (Figure 4.1). Plates move around the Earth’s surface at a rate of a few centimeters a year. This is about the same rate that fingernails grow.

How Plates Move
Convection within the Earth’s mantle causes the plates to move. Mantle material is heated above the core. The hot mantle rises up toward the surface (Figure 4.2). As the mantle rises, it cools. At the surface, the material moves horizontally away from a mid-ocean ridge crest. The material continues to cool. It sinks back down into the mantle at a deep sea trench. The material sinks back down to the core. It moves horizontally again, completing a convection cell.

Seafloor spreading takes place as plates move apart from each other at a mid-ocean ridge. Mantle convection drives seafloor spreading.

Vocabulary

- **convection cell**: Hot material rises and cool material sinks in a circular pattern.
Earth’s plates are shown in different colors. Arrows show the direction the plate is moving.

Plates move for two reasons. Upwelling mantle at the mid-ocean ridge pushes plates outward. Cold lithosphere sinking into the mantle at a subduction zone pulls the rest of the plate down with it.

- **seafloor spreading**: Mechanism for moving continents. The formation of new seafloor at spreading ridges pushes lithospheric plates on the Earth’s surface.

**Summary**

- Plates move by seafloor spreading
- Seafloor spreading is driven by mantle convection.
- Plates move as if on a conveyor belt.

**Practice**

Use the resource below to answer the questions that follow.
• **Tectonic Plate Movement** at [http://www.youtube.com/watch?v=prfgw8uKXA8](http://www.youtube.com/watch?v=prfgw8uKXA8) (3:18)

1. What would the Earth look like without the biosphere and atmosphere?
2. What are plates?
3. How fast are the plates moving?
4. What happens at the ridges?
5. What are subduction zones?
6. What heats Earth’s interior?

**Review**

1. Describe how convection takes place in the mantle.
2. How does mantle convection cause seafloor spreading?
3. How does seafloor spreading move plates?

**References**

2. Christopher Auyeung. CC BY-NC 3.0
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 5.1) 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.
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.


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
Practice

Use this resource to answer the questions that follow.

1. What causes divergence?
2. How is new crust created?
3. What erupts on the ocean floor?
4. How fast does divergence occur?
5. What is formed at a divergent boundary?

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?

References

**Concept 6**  
**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 6.1 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 6.2).

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.
Baja California

Baja California is a state in Mexico just south of California. In the Figure 6.3, 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 6.4.

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.
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

Practice

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. What 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.

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?

References

2. Laura Guerin. . CC BY-NC 3.0
3. Courtesy of NASA. . Public Domain
FIGURE 6.4
Volcanism in Baja California is evidence of rifting.
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 7.1).

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

Practice

Use this resource to answer the questions that follow.
http://www.learner.org/interactives/dynamicearth/slip3.html
1. Describe the motion of transform boundaries.
2. What is a fault?
3. What do transform 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?

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?

References

• 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. The magma rises and erupts, creating volcanoes. These coastal volcanic mountains are found in a line above the subducting plate (Figure 8.1). The volcanoes are 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://
earthguide.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 8.2). The Juan de Fuca plate is created by seafloor spreading just offshore at the Juan de Fuca ridge.

![Cascades Volcanoes Diagram](image)

**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 8.3).

**FIGURE 8.3**

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.


**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**
Practice

Use these resources to answer the questions that follow.
http://www.nature.nps.gov/geology/usgsnps/pltec/converge.html
1. Describe a subduction zone.
2. What forms this subduction zone?
3. How far does the subducting oceanic plate descend?
4. What is formed on the continental plate?
5. Where can an example of this plate boundary be found?

6. What is a locked zone?
7. What is produced when the locked zone is released?

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?

References

3. User:Geographer/Wikipedia. CC BY 1.0
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 9.1)?

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
that most plates are made of different types of crust. This subduction creates the Aleutian Islands, many of which are currently active (see Figure 9.2). 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.

Practice

Use this resource to answer the questions that follow.

http://science7.com/ES-PlateTect-PlateMove.htm

1. What forms where two oceanic plates converge?
2. Explain how an island volcano forms.
3. What is an island arc?
4. Give two examples of island arcs.
5. How is magma produced?

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?
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.

References

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.


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.
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.

Practice

Use these resources to answer the questions that follow.

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?

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?

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?
References

Can plate tectonics explain the differences in these beaches?

Plate tectonics explains why some beaches have lots of cliffs and some do not. A beach with lots of cliffs is near a plate boundary. A gentle beach is not. There are exceptions to this rule, but it works in some cases.

**Continental Margins**

Think of a continent, like North America. Surrounding the continent are **continental margins**. Continental crust grades into oceanic crust at continental margins. Continental margins are under water. Almost all of North America sits on the North American Plate (Figure 11.1). Both sides of the continent have continental margins, but each is very different. One continental margin of North America is an active margin. The other is a passive margin. Can you guess which is which?

**Active Margins**

If a continental margin is near a plate boundary, it is an **active margin**. The continental margin of western North America is near a set of plate boundaries. There are convergent boundaries, like where there is subduction off of the Pacific Northwest. There is a transform boundary, the San Andreas Fault. The small amount of the North American continent that is not on the North American Plate is across the San Andreas Fault. It is on the Pacific Plate. Western North America has a lot of volcanoes and earthquakes. Mountains line the region. California, with its volcanoes and earthquakes, is an important part of this active margin (Figure 11.2).

**Passive Margins**

There are no volcanoes and very few earthquakes on the eastern edge of North America. The continental margin is a smooth transition from continental to oceanic lithosphere. The continental margin there becomes oceanic lithosphere, but both are on the North American Plate. There is no plate boundary. The far eastern edge of the North American Plate is the mid-Atlantic Ridge. The portion of a plate that does not meet another plate has no geological activity. It is called a **passive margin** (Figure 11.3).
FIGURE 11.1
The North American plate and the plates that surround it.

FIGURE 11.2
Big Sur, in central California, has beautiful cliff-lined beaches.
The eastern U.S. is a passive margin. Daytona Beach in Florida is flat and sandy, typical of a passive margin.

**Vocabulary**

- **active margin**: Part of a plate that has a lot of geological activity; this is because this part of the plate meets another plate.
- **continental margin**: Outer edge of a continent where it transitions to oceanic lithosphere; the continental margin is under water.
- **passive margin**: Part of a plate that has no geological activity; this part of the plate is not meeting with another plate.

**Summary**

- Continental margins can be active or passive depending on whether they are near a plate boundary.
- Volcanoes and earthquakes are common at active margins. Active margins are near plate boundaries.
- Passive margins are passive. They have little or no geological activity.

**Practice**

Use the resource below to answer the questions that follow.

- **Features of the Continental Margins** at [http://www.onr.navy.mil/focus/ocean/regions/oceanfloor2.htm](http://www.onr.navy.mil/focus/ocean/regions/oceanfloor2.htm)

  1. What is the continental shelf?
  2. What does the continental shelf contain?
  3. What is the continental slope?
  4. What is the continental margin?
  5. What is the continental rise?

**Review**

1. Describe the continental margin of Western North America.
2. Describe the continental margin of Eastern North America.
3. Why are there mountain ranges at passive margins?

References

1. User: AlexCovarrubias/Wikimedia Commons. . Public Domain
2. Tom Nguyen (Flickr:enviziondotnet). . CC BY 2.0
3. Karen Kleis (Flickr:hollykl). . CC BY 2.0
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 12.1**). 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](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 12.2**). The Hawaiian chain continues into the Emperor Seamounts. The bend in the 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.
The Hawaiian Islands have formed from volcanic eruptions above the Hawaii hotspot.

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 12.3). Volcanic activity above the Yellowstone hotspot can be traced from 15 million years ago to its present location on the North American Plate.

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.

Practice

Use these resources to answer the questions that follow.

http://www.youtube.com/watch?v=D1eibbfAEVk
1. Where are the Hawaiian islands located in relation to plate boundaries?
2. What are hotspots?
3. How do hotspots form volcanoes?
4. What evidence supports the theory that hotspots are stationary?
5. Why is Kauai older than the big island?
6. Why is the big island bigger than Kauai?

   http://www.nps.gov/yell/naturescience/tracking_hotspot.htm

8. What direction is the North American Plate moving? How fast is it moving?
9. When did the McDermmit Volcanic Field erupt?
10. What was the most recent eruption of this hotspot? Where?

**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?

**References**

Earthquakes at Transform Plate Boundaries

- Describe earthquakes that take place at transform plate boundaries.

Would you like to live in San Francisco?

Lots of people live in California for the weather. Transplants from snowy climates think they’ve found paradise in the state’s warm sunshine. What if you got your dream job in San Francisco? Would you take it? Are you afraid enough of the region’s potential for large earthquakes that you wouldn’t? Look at the map of faults in the Bay Area (Figure 13.1) before you decide.

Transform Plate Boundaries

Deadly earthquakes occur at transform plate boundaries. Transform faults have shallow focus earthquakes. Why do you think this is so?
California

As you learned in the chapter Plate Tectonics, the boundary between the Pacific and North American plates runs through much of California as the San Andreas Fault zone. As you can see in the (Figure 13.1), there is more than just one fault running through the area. There is really a fault zone. The San Andreas Fault runs from south to north up the peninsula, through San Francisco, gets through part of Marin north of the bay, and then goes out to sea. The other faults are part of the fault zone, and they too can be deadly.

The faults along the San Andreas Fault zone produce around 10,000 earthquakes a year. Most are tiny, but occasionally one is massive. In the San Francisco Bay Area, the Hayward Fault was the site of a magnitude 7.0 earthquake in 1868. The 1906 quake on the San Andreas Fault had a magnitude estimated at about 7.9 (Figure 13.1). About 3,000 people died and 28,000 buildings were lost, mostly in the fire that followed the earthquake.

Recent California earthquakes occurred in:

- 1989: Loma Prieta earthquake near Santa Cruz, California. Magnitude 7.1 quake, 63 deaths, 3,756 injuries, 12,000+ people homeless, property damage about $6 billion.
- 1994: Northridge earthquake on a blind thrust fault near Los Angeles. Magnitude 6.7, 72 deaths, 12,000 injuries, damage estimated at $12.5 billion.

In this video, the boundaries between three different tectonic plates and the earthquakes that result from their interactions are explored: http://www.youtube.com/watch?v=upEh-1DpLMg (1:59).

FIGURE 13.1
(a) The San Andreas Fault zone in the San Francisco Bay Area. (b) The 1906 San Francisco earthquake is still the most costly natural disaster in California history.
New Zealand

New Zealand also has a transform fault with strike-slip motion, causing about 20,000 earthquakes a year! Only a small percentage of those are large enough to be felt. A 6.3 quake in Christchurch in February 2011 killed about 180 people.

Summary

- Transform fault earthquakes have shallow focus because the plates meet near the surface.
- The San Andreas Fault is actually a fault zone made up of a number of other active faults.
- New Zealand also has a transform plate boundary.

Practice

Use these resources to answer the questions that follow.

- http://www.hippocampus.org/Earth%20Science → Environmental Science → Search: Transform Plates

1. What is a transform boundary?
2. Give an example of where a transform boundary is found.

3. How far does the San Andreas Fault extend?
4. What two plates form the fault?
5. What type of fault is it?
6. What causes an earthquake?
7. What is a creepmeter?
8. How many earthquakes occur at the San Andreas fault each year?

Review

1. Why are earthquakes at convergent plate boundaries sometimes deep, while those at transform plate boundaries are always shallow?
2. Are the earthquakes that take place along the other faults in the San Andreas Fault Zone always smaller than the earthquakes that take place on the San Andreas Fault itself?
3. Do you expect that the quiet along the San Andreas Fault near San Francisco since 1906 means that earthquake activity is calming down along that plate boundary?
References

1. (a) Courtesy of US Geological Survey; (b) Photographed by HD Chadwick and courtesy of National Archives and Records Administration. Public Domain
Earthquakes at Convergent Plate Boundaries

• Describe earthquakes that take place at convergent plate boundaries.

How do earthquakes create refugees?

People who’ve lost their homes in a large earthquake in Pakistan live in a refugee camp, which appears as tents in the photo. Despite suffering the loss of their homes, material possessions, and sometimes loved ones, refugees are often most damaged by the fear that another earthquake could strike. With many people, each aftershock brings renewed terror.

Convergent Plate Boundaries

Earthquakes at convergent plate boundaries mark the motions of subducting lithosphere as it plunges through the mantle (Figure 14.1). Eventually the plate heats up enough to deform plastically and earthquakes stop.

Convergent plate boundaries produce earthquakes all around the Pacific Ocean basin.

Ocean-Ocean: Japan

Earthquakes in Japan are caused by ocean-ocean convergence. The Philippine Plate and the Pacific Plate subduct beneath oceanic crust on the North American or Eurasian plates. This complex plate tectonics situation creates a chain of volcanoes, the Japanese islands, and as many as 1,500 earthquakes annually.

In March 2011 an enormous 9.0 earthquake struck off of Sendai in northeastern Japan. This quake, called the 2011 Tōhoku earthquake, was the most powerful ever to strike Japan and one of the top five known in the world. Damage from the earthquake was nearly overshadowed by the tsunami it generated, which wiped out coastal cities and towns (Figure 14.2). Several months after the earthquake, about 22,000 people were dead or missing, and 190,000
buildings had been damaged or destroyed. Aftershocks, some as large as major earthquakes, have continued to rock the region.


**Ocean-Continent: Cascades**

The Pacific Northwest of the United States is at risk from a potentially massive earthquake that could strike any time. The subduction of three small plates beneath North America produces active volcanoes, the Cascades. As with an active subduction zone, there are also earthquakes. Surprisingly, large earthquakes only hit every 300 to 600 years. The last was in 1700, with an estimated magnitude of around 9. A quake of that magnitude today could produce an
incredible amount of destruction and untold fatalities.

An image of earthquakes beneath the Pacific Northwest and the depth to the epicenter is shown here: http://pubs.usgs.gov/ds/91/.


Continent-Continent: Asia

Massive earthquakes are the hallmark of the thrust faulting and folding when two continental plates converge (Figure 14.3). The 2001 Gujarat earthquake in India was responsible for about 20,000 deaths, and many more people became injured or homeless.

![Damage from the 2005 Kashmir earthquake.](FIGURE 14.3)

In Understanding Earthquakes: From Research to Resilience, scientists try to understand the mechanisms that cause earthquakes and tsunamis and the ways that society can deal with them (3d): http://www.youtube.com/watch?v=W5Qz-aZ2nUM (8:06).

Summary

- Earthquakes occur all along the subducting plate as it plunges into the mantle.
- All three types of convergent plate boundaries produce massive earthquakes.
- Subduction zones around the Pacific Rim are responsible for many of the world’s earthquakes.
Practice

Use this resource to answer the questions that follow.

- [http://www.hippocampus.org/Earth%20Science](http://www.hippocampus.org/Earth%20Science) → Environmental Science → Search: **Convergent Plates**

1. How do convergent plate boundaries occur?
2. What is formed by the continental-continental plate boundaries?
3. Where are these type of boundaries found?
4. What is formed at oceanic-continental plate boundaries?
5. Where are active volcanoes found?

Review

1. Why does a subducting plate produce so many earthquakes and what type of quakes does it produce?
2. What caused the most destruction from the 2011 Japan earthquake and why?
3. Why do you think the Pacific Northwest has such infrequent but exceptionally massive earthquakes? There are several possible reasons.

References

2. Courtesy of Mass Communication Specialist 1st Class Matthew M. Bradley/US Navy. . CC BY 2.0
Climb a volcano... are you mad?

Volcanoes are fun (and difficult) to climb. Climbing in the Cascades ranges in difficulty from a non-technical hike, like on South Sister, to a technical climb on Mount Baker in which an ice axe, crampons, and experience are needed.

Convergent Plate Boundaries

Converging plates can be oceanic, continental, or one of each. If both are continental they will smash together and form a mountain range. If at least one is oceanic, it will subduct. A subducting plate creates volcanoes.

In the chapter Plate Tectonics we moved up western North America to visit the different types of plate boundaries there. Locations with converging in which at least one plate is oceanic at the boundary have volcanoes.
Melting

Melting at convergent plate boundaries has many causes. The subducting plate heats up as it sinks into the mantle. Also, water is mixed in with the sediments lying on top of the subducting plate. As the sediments subduct, the water rises into the overlying mantle material and lowers its melting point. Melting in the mantle above the subducting plate leads to volcanoes within an island or continental arc.

Pacific Rim

Volcanoes at convergent plate boundaries are found all along the Pacific Ocean basin, primarily at the edges of the Pacific, Cocos, and Nazca plates. Trenches mark subduction zones, although only the Aleutian Trench and the Java Trench appear on the map in the previous concept, "Volcano Characteristics."

The Cascades are a chain of volcanoes at a convergent boundary where an oceanic plate is subducting beneath a continental plate. Specifically the volcanoes are the result of subduction of the Juan de Fuca, Gorda, and Explorer Plates beneath North America. The volcanoes are located just above where the subducting plate is at the right depth in the mantle for there to be melting (Figure 15.1).

The Cascades have been active for 27 million years, although the current peaks are no more than 2 million years old. The volcanoes are far enough north and are in a region where storms are common, so many are covered by glaciers. The Cascades are shown on this interactive map with photos and descriptions of each of the volcanoes: http://www.iris.edu/hq/files/programs/education_and_outreach/aotm/interactive/6.Volcanoes4Rollover.swf.

Divergent plate boundaries

At divergent plate boundaries hot mantle rock rises into the space where the plates are moving apart. As the hot mantle rock convects upward it rises higher in the mantle. The rock is under lower pressure; this lowers the melting temperature of the rock and so it melts. Lava erupts through long cracks in the ground, or fissures.

Mid-Ocean Ridges

Volcanoes erupt at mid-ocean ridges, such as the Mid-Atlantic ridge, where seafloor spreading creates new seafloor in the rift valleys. Where a hotspot is located along the ridge, such as at Iceland, volcanoes grow high enough to create islands (Figure 15.3).

Continental Rifting

Eruptions are found at divergent plate boundaries as continents break apart. The volcanoes in Figure 15.4 are in the East African Rift between the African and Arabian plates. Remember from the chapter Plate Tectonics that Baja California is being broken apart from mainland Mexico as another example of continental rifting.

Summary

- Melting is common at convergent plate boundaries.
- Convergent plate boundaries line the Pacific Ocean basin so that volcanic arcs line the region.
- Melting at divergent plate boundaries is due to pressure release.
- At mid-ocean ridges seafloor is pulled apart and new seafloor is created.
FIGURE 15.1
The Cascade Range is formed by volcanoes created from subduction of oceanic crust beneath the North American continent.

Practice

Use this resource to answer the questions that follow.

1. Why does the melted rock rise?
2. What does spreading cause?
3. What happens at plate convergence?
4. How is carbon dioxide released from the rock?
5. How is carbon dioxide returned to the atmosphere?

**Review**

1. What causes melting at convergent plate boundaries?
2. Why are there so many volcanoes around the Pacific Ocean basin?
3. What causes melting at divergent plate boundaries?
4. How does a rifting within a continent lead to seafloor spreading?
FIGURE 15.4
Mount Gahinga in the East African Rift valley.

References

2. Curt Smith. . CC BY 2.0
4. Image copyright PRILL, 2013. . Used under license from Shutterstock.com
Volcanoes at Hotspots

- Explain the relationship between hotspots and volcanic activity away from plate boundaries.

Hawaii is a hotspot, or is it a hot spot?
Both, actually. Hawaii is definitely a hot vacation spot, particularly for honeymooners. The Hawaiian Islands are formed from a hotspot beneath the Pacific Ocean. Volcanoes grow above the hotspot. Lava flows down the hillsides and some of it reaches the ocean, causing the islands to grow. Too hot now, but a great place in the future for beach lovers!

Intraplate Volcanoes

Although most volcanoes are found at convergent or divergent plate boundaries, intraplate volcanoes are found in the middle of a tectonic plate. These volcanoes rise at a hotspot above a mantle plume. Melting at a hotspot is due to pressure release as the plume rises through the mantle.

Earth is home to about 50 known hotspots. Most of these are in the oceans because they are better able to penetrate oceanic lithosphere to create volcanoes. But there are some large ones in the continents. Yellowstone is a good example of a mantle plume erupting within a continent.

Pacific Hotspots

The South Pacific has many hotspot volcanic chains. The hotspot is beneath the youngest volcano in the chain and older volcanoes are found to the northwest. A volcano forms above the hotspot, but as the Pacific Plate moves, that volcano moves off the hotspot. Without its source of volcanism, it no longer erupts. The crust gets cooler and the volcano erodes. The result is a chain of volcanoes and seamounts trending northwest from the hotspot.

The Society Islands are the exposed peaks of a great chain of volcanoes that lie on the Pacific Plate. The youngest island sits directly above the Society hotspot (Figure 16.2).
FIGURE 16.1
Prominent hotspots of the world.

FIGURE 16.2
(a) The Society Islands formed above a hotspot that is now beneath Mehetia and two submarine volcanoes.
(b) The satellite image shows how the islands become smaller and coral reefs became more developed as the volcanoes move off the hotspot and grow older.
The most famous example of a hotspot in the oceans is the Hawaiian Islands. Forming above the hotspot are massive shield volcanoes that together create the islands. The lavas are mafic and have low viscosity. These lavas produce beautiful ropy flows of pāhoehoe and clinkery flows of a’a, which will be described in more detail in Effusive Eruptions.

A hot spot beneath Hawaii, the origin of the voluminous lava produced by the shield volcano Kilauea can be viewed here: http://www.youtube.com/watch?v=byJp5o49IF4 (2:06).

Continental Hotspots

The hotspots that are known beneath continents are extremely large. The reason is that it takes a massive mantle plume to generate enough heat to penetrate through the relatively thick continental crust. The eruptions that come from these hotspots are infrequent but massive, often felsic and explosive. All that’s left at Yellowstone at the moment is a giant caldera and a very hot spot beneath.

Hotspot Versus Island Arc Volcanoes

How would you be able to tell hotspot volcanoes from island arc volcanoes? At island arcs, the volcanoes are all about the same age. By contrast, at hotspots the volcanoes are youngest at one end of the chain and oldest at the other.

Summary

- Volcanoes grow above hotspots, which are zones of melting above a mantle plume.
- Hotspot volcanoes are better able to penetrate oceanic crust, so there are more chains of hotspot volcanoes in the oceans.
- Shield volcanoes commonly form above hotspots in the oceans.

Practice

Use this resource to answer the questions that follow.

1. What is a hotspot?
2. What does a thermal plume allow for?
3. What causes convection?
4. What does the volcano build?
5. What carries the volcanoes away from a hotspot?

**Review**

1. What causes melting at a hotspot?
2. Why are there a relatively large number of hotspots in the Pacific Ocean basin?
3. Why do you think there are so many hotspots at mid-ocean ridges; e.g. four along the Mid-Atlantic Ridge and two at the East Pacific Rise?

**References**

2. (a) Holger Behr (User:Hobe/Wikimedia Commons); (b) Courtesy of Johnson Space Center/NASA’s Earth Observatory. . Public Domain
Volcanic Landforms

- Identify and describe landforms created by volcanic activity.

Why is the Republic of Indonesia made of 17,508 islands?

Around the Pacific Rim is Indonesia, a nation built from the dotted volcanoes of an island arc. Indonesia is distinctive for its rich volcanic soil, tropical climate, tremendous biodiversity, and volcanoes. These volcanoes are in Java, Indonesia.

Landforms from Lava

Volcanoes and Vents

The most obvious landforms created by lava are volcanoes, most commonly as cinder cones, composite volcanoes, and shield volcanoes. Eruptions also take place through other types of vents, commonly from fissures (Figure 17.1). The eruptions that created the entire ocean floor are essentially fissure eruptions.

Lava Domes

Viscous lava flows slowly. If there is not enough magma or enough pressure to create an explosive eruption, the magma may form a lava dome. Because it is so thick, the lava does not flow far from the vent. (Figure 17.2).

Lava flows often make mounds right in the middle of craters at the top of volcanoes, as seen in the Figure 17.3.
FIGURE 17.1
A fissure eruption on Mauna Loa in Hawaii travels toward Mauna Kea on the Big Island.

FIGURE 17.2
Lava domes are large, round landforms created by thick lava that does not travel far from the vent.

FIGURE 17.3
Lava domes may form in the crater of composite volcanoes as at Mount St. Helens.
Lava Plateaus

A lava plateau forms when large amounts of fluid lava flow over an extensive area (Figure 17.4). When the lava solidifies, it creates a large, flat surface of igneous rock.

![Figure 17.4](image1)

Layer upon layer of basalt have created the Columbia Plateau, which covers more than 161,000 square kilometers (63,000 square miles) in Washington, Oregon, and Idaho.

Land

Lava creates new land as it solidifies on the coast or emerges from beneath the water (Figure 17.5).

![Figure 17.5](image2)

Lava flowing into the sea creates new land in Hawaii.

Over time the eruptions can create whole islands. The Hawaiian Islands are formed from shield volcano eruptions that have grown over the last 5 million years (Figure 17.6).
Landforms from Magma

Magma intrusions can create landforms. Shiprock in New Mexico is the neck of an old volcano that has eroded away (Figure 17.7). The volcanic neck is the remnant of the conduit the magma traveled up to feed an eruption.
Summary

- Landforms created by lava include volcanoes, domes, and plateaus.
- New land can be created by volcanic eruptions.
- Landforms created by magma include volcanic necks and domes.

Practice

Use this resource to answer the questions that follow.

1. What type of lava is produced by volcanoes?
2. How did the columns in the video form?
3. How was Fingal’s cave formed?
4. Describe how the basalt lava flows?
5. How does basalt behave when it has a lot of gas trapped within it?

Review

1. What is Shiprock and how did it form?
2. How do lava plateaus form?
3. What types of landforms are created by very viscous magma?

References

5. Vlad and Marina Butsky. . CC BY 2.0
6. Courtesy of NOAA Coastal Services Center Hawaii Land Cover Analysis project. . Public Domain
7. Bowie Snodgrass. . CC BY 2.0