Integrated Science

Science course from Educational Options

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Lesson 11: The Earth

Objectives

By the end of this lesson, students will be able to:

- summarize how the Earth's composition came about during the formation of the solar system
- identify the Earth's layers and plate boundaries
- evaluate the theory of continental drift
- identify the causes of earthquakes and distinguish between types
- explain how volcanic eruptions are related to plate tectonics

Click here for the course glossary

Introduction

> For several days steeper inclines, some even frightfully near to the perpendicular, brought us deeper and deeper into the mass of the interior of the Earth . . . By the 7th of August our successive descents had brought us to a depth of thirty leagues [104 mi]; that is, that for a space of thirty leagues there were over our heads solid beds of rock, ocean, continents, and towns.
>
> **Chapter XXVI. The Worst Peril of All**
> ***Journey to the Center of the Earth* by Jules Verne**

Snæfellsjökull, the real volcano located in Iceland that Jules Verne's fictional characters used as a passage to the center of the Earth

Jules Verne's classic *Journey to the Center of the Earth* is a fictional account of three scientists who discover a passageway to Earth's center. The characters' tale starts at the opening of a volcano in Iceland and ends across the globe in Italy. Along the journey, the scientists encounter many supernatural wonders, including prehistoric beasts, subterranean oceans, giant mushroom forests, and even a possible proto-human civilization.

Although Verne's harrowing account of the Earth's center is only fantasy, Verne's novel brings up an important question. What forms the Earth's interior? In this lesson you will learn about how the Earth was formed and the composition of the Earth's interior and surface. This lesson will also explore how the internal system of the Earth operates.

How Was the Earth Formed?

Our solar system is made up of planets, moons, dwarf planets, asteroids, and other bodies that orbit the Sun. Scientists think that all of these celestial bodies, including the Earth, started from a single mass of space gas and dust particles. Therefore, to understand how the Earth was formed, we must examine how the solar system was created.

The Protostar and the Planetary Disk

The solar system began forming about 4.6 billion years ago. The Earth emerged from this process. Scientists believe that the solar system originated from the explosion of a giant star combining with interstellar gas and dust particles. This is called the nebular hypothesis.

NASA image of a protostar and its surrounding disk.

In the nebular hypothesis, the formation of a solar system requires specific circumstances. A combination of two natural occurrences allowed our solar system to form. The first of these phenomena is the presence of space particles. Throughout space, there are collections of gas and dust particles. Often these particles will form into a cloud known as a **nebula**.

The second condition that was key in the formation of our solar system was the occurrence of a **supernova**. A supernova is the last stage in the life cycle of a star. During a supernova, a **supergiant** star collapses and spews massive amounts of energy into the surrounding area.

Most scientists believe that the interaction between these two occurrences played a pivotal role in the formation of our solar system. According to this theory, the intense pressure of a large supernova explosion caused the particles of a nebula to condense and rotate.

As the dust cloud rotated and condensed, its gravitational pull increased. This increase in **gravity** allowed the cloud to pull more material into its center. The center of the nebula became hotter and denser. As it gained mass and density, it spun faster. Eventually, the nebula took on a flatter, oval form. This process is similar to the way a ball of dough changes when a baker spins it to make a pizza crust. The nebula then separated into two parts: a dense, hot core called a **protostar** and a surrounding ring, or **planetary disk**.

After approximately 100 million years of spinning, the temperature and pressure in the core of the protostar was enough that a star formed, the Sun. During this time and after, the remaining particles in the planetary disk were colliding and sticking together. They cooled and condensed into larger bodies that would form into planets and other celestial bodies that revolve around the Sun.

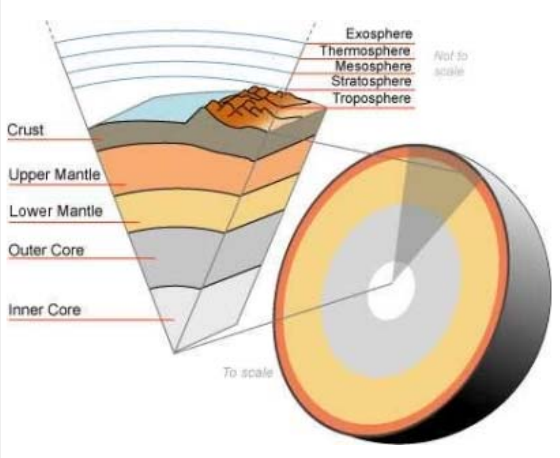
The Earth's Interior and Surface

While the Earth appears to be one solid sphere similar to this basketball (left), it is actually more like the layers of the peach (right), with the skin as the Earth's thin crust, the flesh as the mantle, and the pit as the core.

When you look at the Earth, it appears to be one solid sphere. However, the Earth is actually separated into layers. There are four different layers of Earth: the inner core, the outer core, the mantle, and the crust. All of these layers play important roles in shaping the Earth’s surface.

The innermost layer of the Earth is the **core**. The core is thick and makes up one third of the Earth's total mass. The core is separated into two parts, the **inner core** and **outer core**. Both of these layers are composed of a mixture of iron and nickel. However, the inner core is mostly iron, while the outer core contains more nickel.

The inner core is under intense pressure. So much pressure that the inner core is solid even at temperatures between 5,000° C and 6,000° C. It is about 1,216 km thick. The outer core is 2,270 km thick and distinct from the inner core because it is liquid. It has temperatures between 4,000° C and 5,000° C. At its hottest points, the core is almost as hot as the surface of the Sun!



Layers of the Earth

The layer directly above the core is the **mantle**. The mantle is the thickest of the Earth's layers, measuring about 2,900 km at its thickest parts. There are two parts to the mantle, the lower mantle and the upper mantle. The majority of the mantle is made up of the viscous, semi-solid rock found in the lower mantle. Little is known about this layer. The upper mantle has three sections. Just above the lower mantle is the transition zone. Above the transition zone, between 100 km and 200 km, is a layer of very plastic, nearly molten rock. This melted rock is called **magma**. Magma moves about below the Earth's crust, depending on the temperature and pressure of its surroundings. Magma that has risen to the Earth's surface by passing through warm or broken rock is called **lava**. The upper layer of the mantle is hard and **brittle**.

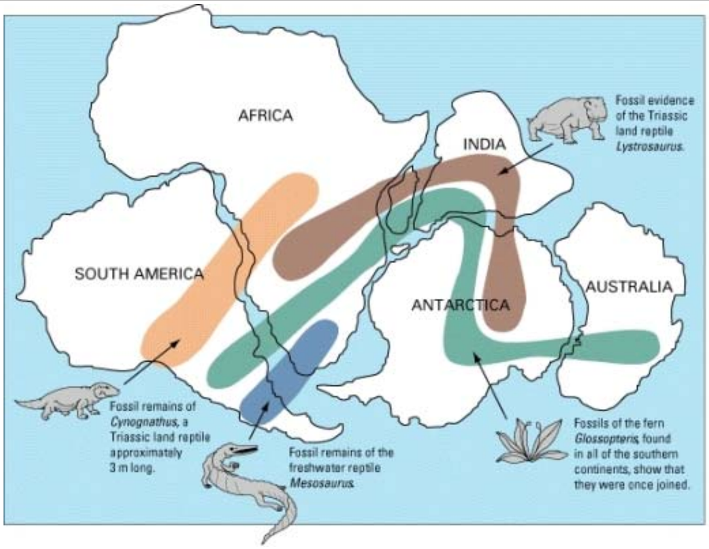
The outer layer of the Earth is called the **crust**. The crust is the thinnest layer of the Earth. The thickness of the crust varies anywhere from 5 km to 75 km in depth. The Earth's surface is made up of two different types of crust: continental crust and oceanic crust. Continental crust makes up the dry land on Earth. The continental crust is old, thick, and brittle. Oceanic crust is the layer of the crust that lies below the ocean. While oceanic crust is much younger and thinner than continental crust, it is much denser. The majority of the Earth, about 60%, is composed of oceanic crust. The Earth's crust, acting with natural forces, is essential in the formation of the natural features found on the Earth's surface. All these layers interact to shape the Earth’s surface.

What Is the Theory of Plate Tectonics?

Imagine a world with one giant supercontinent on which all organisms lived. This idea may sound like the makings of a great fantasy movie, but it is actually how land on Earth once looked. Two hundred million years ago the Earth looked very different. How did the supercontinent become the seven continents we know today? The study of plate tectonics aims to account for the changes in and movement of the Earth's surface.

Pangaea and Continental Drift

The first scientist to propose the idea of a supercontinent was Alfred Wegner in 1915. Wegner suggested that the continents of Earth were initially joined together as one giant landmass that later broke apart into pieces. Wegner named this landmass **Pangaea**, a combination of the Greek words for "all" (pan) and "earth" (gaia).



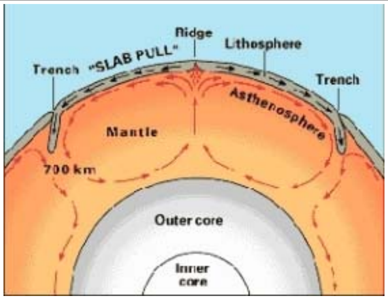
The type and location of the fossils helped Wegner formulate his theory on continental drift.

Think About It

The magma of the lower mantle plays a critical role in plate tectonics. It is important to the creation of new land formations, as well as the movement of the Earth's plates. How would plate tectonics change if the mantle was completely solid? How might the Earth's surface look different?

Plate Movement and Convection Currents

So what makes the Earth's plates move? Each layer of the Earth's interior plays an important role in plate movement. In addition to the four layers mentioned already in this lesson, there are two other layers that assist in plate movement. These layers are called the **asthenosphere** and the **lithosphere**.



Notice how new crust material is created at openings between plate boundaries and old crust material is recycled when it returns to mantle.

The lithosphere is composed of the crust and hard upper layer of the mantle. It is broken into several large plates. The lithospheric plates rest on top of the asthenosphere. The asthenosphere is the molten, magma producing layer of the upper mantle. This layer, as well as the lower mantle below it, are heated by the thermal energy created by the inner and outer cores. The result is that the asthenosphere is constantly moving. The magma moves within the asthenosphere in a circular pattern called **convection currents**. In a convection current, hot magma moves to the top, cools down, and sinks back to the bottom of the asthenosphere. The plates move with the motion of magma. Remember, this movement is very slow.

Recently, scientists have accepted subduction as an important force in plate movement. Subduction occurs when the magma of the mantle erupts to the Earth's surface and provides new material for the crust to expand at openings in between plates. In return, when the crust is pushed back into the mantle, it melts, providing the mantle with more magma. This process is in constant motion, producing and recycling the Earth's surface. This process is extremely slow and is only noticeable over millions of years. On average, plates only move 4 cm to 7 cm over an entire year!

There are three major types of plate movement. The first type of plate movement occurs when plates move towards each other. This can have two different outcomes: *subduction*, when one plate slides underneath another plate, or *convergence*, when plates push against each other. The second type of plate

Debates in Science:
The Continental Drift Theory

Alfred Wegner examined the remains of various plants and animals from Africa, Australia, India, and South America. Wegner found that many of the fossils he collected from these different geographic locations were similar. Wegner also noticed that the rock samples were similar in composition. From these findings, Wegner deduced that about 225 million years ago the seven continents of the Earth originally came from one single continent. Wegner named his findings the **Continental Drift Theory**.

The next piece of the puzzle was to explain how the super continent of Pangaea broke apart into the seven continents found on the Earth today. The discovery of plate tectonics answered this question. During the 1950s and 1960s, scientists discovered that the Earth's crust was not formed in one giant piece, but several large pieces called plates. **Plate tectonics** is the process by which the Earth's plates continuously move over top of the mantle.

movement is spreading. Two plates move away from each other, allowing magma to erupt and fill the gap between the two plates. The final type of plate movement is faulting, or when two plates slide laterally in opposite directions.

How Can We Observe Continental Drift?

When you look at a globe, what do you see? Perhaps you notice the Alps of northern Italy. Or maybe you see the island chain of the Philippines located in the western Pacific Ocean. Have you ever wondered how these land formations were made? All these natural formations are the work of plate tectonics.

This map shows the major plate boundaries of Earth. Each colors represent a different plate. Notice how some plates are very large, while others are quite small.

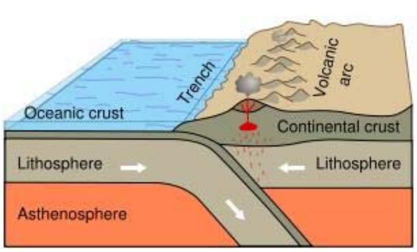
The Earth's crust is separated into seven major plates and several more minor ones. There are two kinds of plates: oceanic, which are located under the oceans, and continental plates, which make up the surface of the Earth.

The plates differ in size as well. Some plates are very large, such as the Pacific plate which measures 14,000 km wide. However, other plates are much smaller. One of the smallest plates is the Cocos plate. The Cocos plate measures about 2,100 km wide, which is less than half of the width of Australia.

The section where two plates meet is called a boundary. This is where the plate movements described earlier occur. As you learned, the plates that make up Earth's crust do not move together in one uniform direction, but can move in several different directions. There are three types of boundaries, depending on the direction that the plates move: converging (towards each other), diverging (away from each other), or transforming (slide past each other). The natural features and phenomena of Earth's crust are the result of these three types of plate boundaries.

Convergent Plate Boundaries

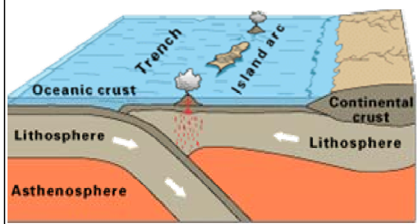
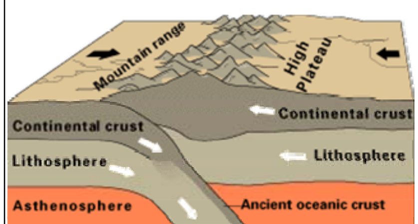
When two plates collide, they create a **convergent plate boundary**. At this type of boundary, one plate is pushed under the other creating a **subduction zone**. The material from the plate that is pushed under the other is melted and recycled back into the Earth's interior inside the mantle. However, because continental plates are much denser than oceanic plates, there are three possible outcomes at a convergent plate boundary.

Plates Involved	**Description of Collision**
 **One Oceanic and One Continental Plate**	The heavier oceanic plate always slides under the continental plate. The pressure that the continental plate is under causes it to fold and fault. This can create a series of hills or mountains. The diving oceanic plate generates heat, which often gives rise to volcanoes. The Andes Mountains, located in western South America, were created by the collision of the Nazca oceanic plate and the South

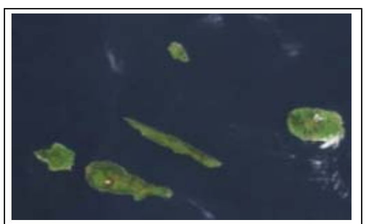
Try This!

The Pangaea Puzzle
Directions: Click **here** and print a copy of the world map above. Cut out each continent from the map. Try to arrange the continents so that each piece fits together like the pieces of a puzzle.

Do all the pieces fit together perfectly? Why do you think some pieces fit together better than others? What natural processes that you have learned about in this lesson could explain why some of the pieces do not fit together?

	American continental plate.
 **Two Oceanic Plates**	When two oceanic plates collide, one plate slides underneath the other. A deep valley called a **trench** usually forms at the point of collision. The heat generated by the diving plate often creates a series of volcanoes. **Volcanoes** are the build up of hardened lava at openings in the Earth's crust from where magma is able to erupt into lava. The Mariana Trench, created by subduction of the Pacific plate under the Philippine plate, is an example of such a trench system. Sometimes these volcanoes form into island chains.
 **Two Continental Plates**	When two continental plates collide, they resist subduction. This is because the continental rocks are fairly light. The pressure from the bottom plate pushing up against the upper plate causes the land to rise. Most of the world's mountain ranges were created by this type of collision. The massive and still growing Himalayan Mountains are the result of the collision of the Indian and Eurasian continental plates.

Divergent Plate Boundaries



A view of the Azores from space. The Azores are islands formed from where the peaks of the Mid-Atlantic Ridge reached the surface.

Another kind of plate movement is when two plates move away from each other, or diverge. This type of plate boundary is called a **divergent plate boundary**. Divergence mainly occurs between two oceanic plates.

When two plates pull apart from each other, the magma from the mantle rises to fill the gap. Magma that erupts onto the Earth's surface hardens and over time builds up to form volcanic mountains. This creates chains of underwater volcanic mountains called **oceanic ridges**. The largest oceanic ridge is not one ridge but a series of ridges collectively called the mid-ocean ridges. These underwater mountain ranges are easily the longest mountain range in the world, collectively measuring 60,000 km in length. The Mid-Atlantic Ridge is part of the mid-ocean ridge located in the center of the Atlantic Ocean. When these ridges rise above sea level, they create volcanically active islands.

The Azores are a group of volcanically active islands that developed from the Mid -Atlantic Ridge.

Although most divergent plate boundaries are located under the ocean, divergence happens on land as well. When two continental plates separate, they create a **rift valley**. A rift valley is created when the plate under a continent is stretched until it breaks and then sinks. The Great Rift Valley is a 6,440 km rift valley that stretches from Syria in southwestern Asia to southeastern Africa, ending in Mozambique.

Transform Plate Boundaries

The last type of plate movement occurs when two plates slide past each other in opposite directions. When two plates move horizontally, they create a **transform plate boundary**. Imagine that your hands are tectonic plates. Place them together, like you are clapping. Now slide them against each other. This is how a transform boundary works. Try rubbing your hands together faster. Do you feel the heat energy created by moving your hands against each other? What do you think happens to the plates when that same energy is created between them?

When two plates slide against one another, the energy builds up. When the pressure of that build up becomes too great, it releases in the form of an **earthquake**. An earthquake is the sudden release of stored energy. Depending on the pressure caused by plate movement, earthquakes range in magnitude, or strength. The faults around the plates near Asia account for 80% of the world's earthquakes. Japan alone experiences over 1,000 earthquakes a year!

The 2004 tsunami near Sumatra was a primary effect of an underwater earthquake in the Indian Ocean. The map above shows the location of the earthquake as well as the countries affected by the tsunami.

Earthquakes

There are two types of earthquakes related to plate tectonics. The first type of earthquake is a **tectonic earthquake**. A tectonic earthquake occurs where two plates meet, like at a transform plate boundary. Tectonic earthquakes are the most common type of earthquakes, occurring along plate boundaries.

The second type of earthquake that is caused by plate tectonics is a **volcanic earthquake**. Volcanic earthquakes are the result of the pressure placed on the Earth's crust when magma pushes through the Earth's interior. During a volcanic eruption, the pressure from the magma pushing through the crust causes it to break, releasing energy. Volcanic earthquakes are only common in areas with active volcanoes. They can be a warning sign that a volcano will soon erupt.

Earthquakes can be very destructive. The effects of earthquakes are classified into two categories, primary and secondary. Primary effects are damages that occur as a direct result of the earthquake, such as property damage, fires, tsunamis, or the loss of life. Secondary effects are losses that occur as an indirect result of the earthquake, including economic loss, disease, and lack of fresh water or food.

The tsunami that occurred off the shore of the Indonesian island of Sumatra in 2004 demonstrates the devastation that can be caused by both primary and secondary effects. The tsunami was generated by an undersea earthquake that occurred in the Indian Ocean. Fourteen different countries off the coasts of northeast Africa and southeast Asia were directly affected. While the impact of the primary effect, the tsunami, was the most devastating, many more lives were lost as the result of secondary effects, such as the spread of disease and the lack of fresh water and food.

Making Connections

Could you have ever imaged that what is occurring hundreds of miles below the surface directly influences the world around you? From the Himalayan Mountains of Asia to the volcanic islands of Hawaii, formations on the Earth's surface are created and destroyed by plate tectonics. Plate tectonics are constantly changing the Earth's surface, shaping the world around you.

In this lesson, you learned about the Earth's interior and how it operates. You also learned that evidence of the Earth's internal process is found on Earth today in the form of different natural formations. In the next lesson, you will learn more about the composition of the Earth's surface.

Practice Problems

Answer each question in your notebook. Click on the "Check Answers" button to check your answers.

1. What are the three ways that plate boundaries behave?

2. Starting at the inner most layer, what is the correct order of the Earth's layers?
a. inner core, outer core, upper mantle, lower mantle, crust
b. inner core, outer core, lower mantle, upper mantle, crust
c. outer core, inner core, upper mantle, lower mantle, crust
d. outer core, inner core, lower mantle, upper mantle, crust

3. What is the primary difference between tectonic earthquakes and volcanic earthquakes?

Check Answers Hide Answers

Homework Questions

Click here to view a printable copy of this homework assignment.

Earthquakes and volcanic eruptions occur every day. Some are quite small and barely noticeable, while others cause widespread damage and destruction. Research a famous earthquake or volcanic eruption and write a two paragraph response about your selected earthquake or eruption.

The 1980 eruption of Mt Saint Helens

The first paragraph of your response should describe the earthquake or eruption you chose, including the date, location, magnitude, and affected areas. The second paragraph should relate to how the earthquake or volcanic eruption you selected is evidence of plate movement and tectonics.

Useful Resources:

Information on volcanoes and earthquakes from the United States Geological Survey can be found at the two following sites:

http://earthquake.usgs.gov/

http://volcanoes.usgs.gov/

Click here for the course glossary