U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Marine Fisheries Service

Lesson 13: Plate Tectonics I

Overview

Lesson 13 introduces students to geological oceanography by presenting the basic structure of the Earth and the properties of Earth's primary layers. Students learn the structure and composition of oceanic and continental crust and the theory of plate tectonics. In the activity, students calculate the rate of movement of the Pacific Plate using information about the age of the Hawaiian Islands.

Lesson Objectives

Students will:

1. Describe the basic characteristics of Earth's three layers: crust, mantle and core
2. Define the lithosphere and asthenosphere
3. Calculate the rate of movement of the Pacific Plate

Lesson Contents

1. Teaching Lesson 13
    a. Introduction
    b. Lecture Notes
    c. Additional Resources
2. Teacher's Edition: How Fast Does the Pacific Plate move?
3. Student Activity: How Fast Does the Pacific Plate move?
4. Student Handout
5. Mock Bowl Quiz

Standards Addressed

National Science Education Standards, Grades 9-12
Unifying concepts and processes
Physical science
Earth and space science

Ocean Literacy Principles
The Earth has one big ocean with many features

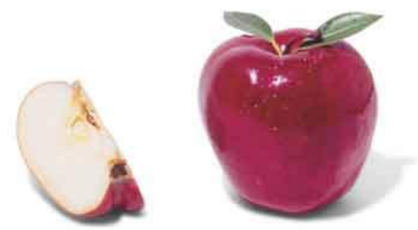
DCPS, High School
Earth Science
ES.7. Plate tectonics operating over geologic time has altered the features of land, sea and mountains on the Earth's surface

Lesson Outline[1]

I. Introduction

Introduce the lesson using a demonstration of Earth's internal layers. You can use an apple, or any other type of fruit with a thin outer skin, relatively thick center and a core. For example, an avocado, plum or peach would also work[2].

1. Show the students the uncut apple. Tell them that the apple is a model that can demonstrate how Earth actually has different layers, though it may appear to be one uniform substance. Explain that understanding these basic layers will help them understand the geology of the Earth and its oceans.



2. Make a triangular slice in the apple so that you remove ¼ of the apple all the way down to the core. Show the students the apple while you explain the layers.

3. The Earth is composed of three layers: the crust, mantle and the core. The Earth's crust is like the skin of the apple, very thin in comparison to the other three layers. There are two types of crust: continental crust (beneath Earth's land surface) and oceanic crust (beneath the ocean floor). The continental crust is lighter (similar to granite) and the oceanic crust is denser (more like basalt).

4. The mantle is the relatively thicker layer beneath the crust, represented by the flesh of the apple. It is composed of molten rock similar in composition to very hot asphalt. The crust and the rigid, outer zone of the mantle make up a layer that is called the **lithosphere**.

5. The zone directly under the lithosphere is made of a flowing, denser layer called the **asthenosphere**. The outer core, represented by the core of the apple, is composed of very hot liquid metals, nickel and iron. The inner core is composed of the same nickel and iron but in a solid state because of intense pressure.

II. Lecture Notes

Present the following information using the PowerPoint for Lesson 13 (File:Lesson 13 – Plate Tectonics I.ppt). Distribute the Student Handout before you begin for students to take notes on key information.

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[1] Unless otherwise indicated, all websites provided or referenced in this guide were last accessed in November 2010.
[2] Photo: International Trade Organization, http://www.trade.gov/exportamerica/NewOpportunities/no_diagnostics.html

Visualizing Earth's layers (slide 4)

1. The Earth is composed of three primary layers: the core, the liquid-like mantle and the rigid outer crust.
2. If you took a cross-section of the Earth you would see that the crust lays on top of the mantle and is very thin relative to the mantle

There are two types of crust: oceanic crust and continental crust (slide 5)

1. Oceanic crust is found beneath the deep ocean and continental crust includes the continents and continental shelves.

2. These two different types of crust have different properties. Oceanic crust tends to be thinner, more dense and younger (meaning that is was formed more recently) than continental crust.

The lithosphere and asthenosphere (slide 6)

1. It is important to understand the difference between the lithosphere and the asthenosphere.

2. The lithosphere is composed of the topmost portion of the mantle and the crust. It is rigid and rests on a relatively weaker, plastic material called the asthenosphere (literally meaning "weak sphere").

What is a plate? (slides 7-10)

1. The lithosphere is not one continuous layer, but rather a puzzle-like configuration of many distinct pieces. These distinct pieces are known as plates.

2. Plates can contain only oceanic crust, only continental crust or both crust types.

3. Because they rest on the asthenosphere which is relatively soft and constantly in motion, plates are also always in motion with relation to one another even though this motion is very slow.

III. Additional Resources

1. Lesson plans and teaching tools
   http://free.ed.gov/keywords.cfm?keyword_id=675&res_feature_request=1

2. Background information
   http://volcano.oregonstate.edu/vwdocs/vwlessons/plate_tectonics/part1.html

Tracking the Hawaiian Islands: How Fast Does the Pacific Plate Move?

Overview

In the activity, students use information about the average age of the Hawaiian Islands and the distances between the islands to calculate the average rate of movement of the Pacific Plate. Using this rate, students then calculate how far the Pacific Plate has moved in the average student's lifetime (assumed to be 17 years).

Background

You know that the Earth's crustal plates are always moving, but how fast? Each of Earth's plates can move at a different speed and these speeds can change over geological time. But by studying rock formations along boundaries, scientists can figure out how fast each plate has been moving on average over a given time period. Today, students are going to figure out how fast the Pacific Plate is moving using information about the Hawaiian Islands.

This map shows the approximate location (marked with an X) of the Hawaiian Islands on the Pacific Plate. The arrow shows the approximate direction of plate movement. Note that the hotspot is *not* at a plate boundary.

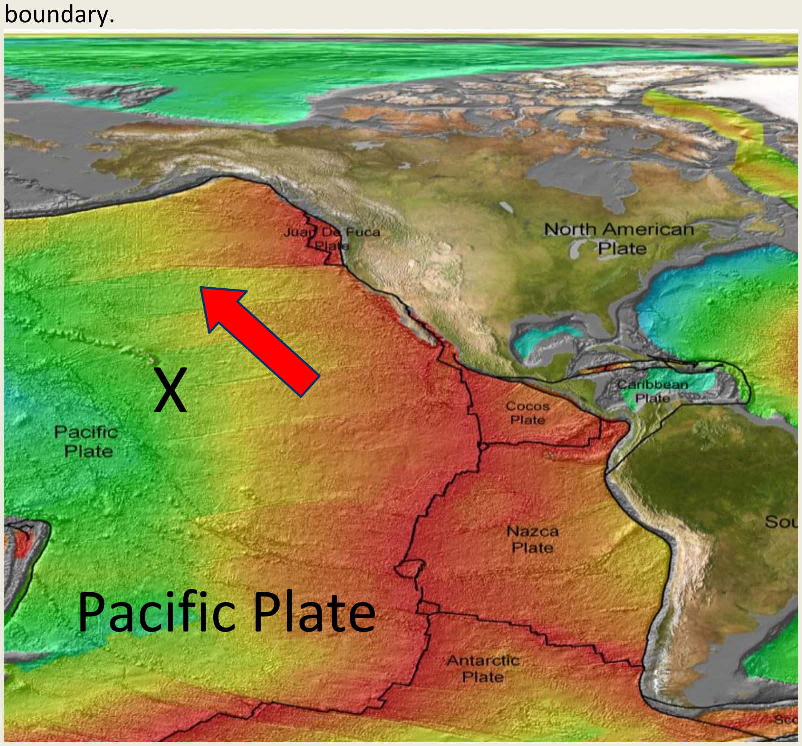

Photo: NOAA

Have you ever visited a "hot spot?"

A scientist named J. Tuzo Wilson once noticed that some volcanoes occur in lines or rows. His theory was that the volcanoes form as small melting areas in the mantle (literally "hot" spots) and cause magma plumes to break through the crust. As the plate above the hot spot moves, new volcanoes form in a line or chain. The Hawaiian Islands are a classic example of a volcanic island chain formed by the Pacific Plate moving over a hotspot (see picture at left[3]). Do you know of any other examples of hot spots?[4]

[3] Photo: NOAA, http://www.ngdc.noaa.gov/mgg/ocean_age/data/2008/ngdc-generated_images/whole_world/2008_age_of_oceans_plates.jpg

[4] National Marine Educators Association. 2010. *Life on an Ocean Planet*. Current Publishing Corps, Santa Margarita, CA. 598pp.

Procedure

1. Divide your class into groups of 4-5 students per group.

2. Before the groups begin working, ask each student to guess how far the Pacific Plate has moved over the average student's lifetime (17 years). Have students write their answers down, and reward whichever student in each group guessed the closest.

3. Distribute the Student Activity and instruct students to read the background and follow the procedures.

4. Give students a ruler to measure the distance between the islands as indicated in the instructions.

5. First, students are instructed to calculate **rate** of plate movement. Remind students that rate is equal to how far an object has moved over a certain amount of time (like miles per hour). Scientists usually report the rate of plate movement in centimeters per year (cm/yr). Once we know the rate, we can multiply by the average lifetime of a student (17 years) to determine how far (in cm) the Pacific Plate has moved in this time.

   Rate = Distance/Time

6. Students use the Hawaiian Island Map to see the main islands in the Hawaiian Island chain. The oldest islands are the furthest to the West from the hot spot. As the Pacific Plate moves, newer islands form. Hawaii is the youngest island and it is still being formed today; thus, Hawaii is currently at the hot spot location. Students are given ages for three of the islands: Kauai, Molokai and Hawaii. With the scale on the map, they can figure out the distances between each island and the hot spot. Therefore students know how far the plate moved from the hotspot over time. This is all they need to calculate the rate!
   a. Using the scale on the map, students find the distance from the middle of Hawaii to the middle of Molokai and fill the information in the first data table on the Data Worksheet.

   b. Next, students calculate the rate at which the Pacific Plate moved since the formation of Molokai by dividing the distance by the age of Molokai. Students should fill the value in on their data table.

   c. Students complete the same procedure to determine the rate of movement since the formation of Oahu and the formation of Kauai.

7. After students have found the rates of movement since the formation of the three islands, they should average the numbers (add them and divide by three) to find the average rate of the Pacific Plate.

8. Finally, students convert their answers from km/yr to cm/yr by multiplying your average by 100,000.

9. Students should fill out the second table on the Data Worksheet to determine how far the Pacific Plate has moved in 17 years.

Answer key
Keep in mind the measurements won't be exact and students' answers may vary, but the answers should all be in the ballpark of the estimates given in the answer table below.

Island	Distance	Age	Rate(Distance/Age)
Molokai	**210km**	1.8 million years	**11.7cm/yr**
Oahu	**300km**	3.3 million years	**9.1cm/yr**
Kauai	**500km**	5.6 million years	**8.9cm/yr**
		AVERAGE	**9.9cm/yr**

Scientific estimates for the rate range between 10.6-10.75 cm/yr for this Plate at this time[5]. The estimates above were derived using the same map your students will be using. As long as their estimates are somewhere around 10 for an average, they most likely did the exercise correctly.

Average rate (cm/yr)	Time (yr)	Distance (Rate * Time)
9.9	17	**170cm**

170cm is about five and a half feet (170*0.0328=5.576). After awarding the students who guessed closest, help students visualize how far the Plate has moved since they were born by measuring out 170cm on the classroom floor or vertically on the wall. You can also tell students that human fingernails grow around the same rate on average (between 1-10cm/yr). This may help students think about plate movement in relatable terms.

[5] www.usgs.gov

Tracking the Hawaiian Islands: How Fast Does the Pacific Plate Move?

You know that the Earth's crustal plates are always moving, but how fast? Each of Earth's plates can move at a different speed and these speeds can change over geological time. But by studying rock formations along boundaries, scientists can figure out how fast each plate has been moving on average over a given time period. Today, you're going to figure out how fast the Pacific Plate is moving using information about the Hawaiian Islands.

This map shows the approximate location (marked with an X) of the Hawaiian Islands on the Pacific Plate. The arrow shows the approximate direction of plate movement. Note that the hotspot is *not* at a plate boundary.

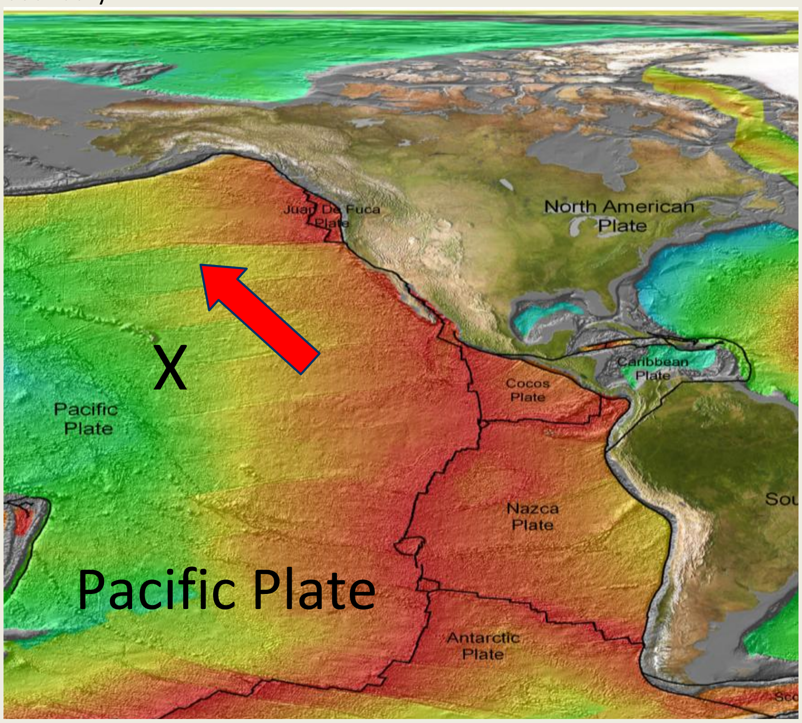

Photo: NOAA

Have you ever visited a "hot spot?"
A scientist named J. Tuzo Wilson once noticed that some volcanoes occur in lines or rows. His theory was that the volcanoes form as small melting areas in the mantle (literally "hot" spots) and cause magma plumes to break through the crust. As the plate above the hot spot moves, new volcanoes form in a line or chain. The Hawaiian Islands are a classic example of a volcanic island chain formed by the Pacific Plate moving over a hotspot (see picture at left[6]). Do you know of any other examples of hot spots?[7]

Measuring the rate of the plate movement
Are you ready for a challenge against your group members?

1. Assume the average age of the students in your group is 17. Over the average student's current lifetime, how far do you think the Pacific Plate has moved? Write down your

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[6] Photo: NOAA, http://www.ngdc.noaa.gov/mgg/ocean_age/data/2008/ngdc-generated_images/whole_world/2008_age_of_oceans_plates.jpg
[7] National Marine Educators Association. 2010. *Life on an Ocean Planet*. Current Publishing Corps, Santa Margarita, CA. 598pp.

answer in feet and hand it to your teacher before beginning the calculations. The student who guessed the closest will get a prize!

How are we going to determine the winner?

Rate = Distance/Time

First, we need to know the **rate** of plate movement. Remember that rate is equal to how far an object has moved over a certain amount of time (like miles per hour). Scientists usually report the rate of plate movement in centimeters per year (cm/yr). Once we know the rate, we can multiply by the average lifetime of a student (17 years) to determine how far (in cm) the Pacific Plate has moved in this time.

2. Calculate the rate

We are going to calculate the average rate of the Pacific Plate over the past ~5 million years using the age and location of three Hawaiian Islands.

The Hawaiian Island Map (next page) shows the main islands in the Hawaiian Island chain. The oldest islands are the furthest to the West from the hot spot. As the Pacific Plate moves, newer islands form. Hawaii is the youngest island and it is still being formed today; thus, Hawaii is currently at the hot spot location. You have been given ages for three of the islands: Kauai, Molokai and Hawaii. With the scale on the map, you can figure out the distances between each island and the hot spot. Therefore you know how far the plate moved from the hotspot over time. This is all you need to calculate the rate!

a. Using the scale on the map, find the distance from the middle of Hawaii to the middle of Molokai. Fill the information in the first data table on your Data Worksheet.

b. Calculate the rate at which the Pacific Plate moved since the formation of Molokai by dividing the distance by the age of Molokai. Fill the value in on your data table.

c. Complete the same procedure to determine the rate of movement since the formation of Oahu and the formation of Kauai.

d. After you have found the rates of movement since the formation of your three islands, average the numbers (add them and divide by three) to find the average rate of the Pacific Plate.

e. Finally, convert your answer from km/yr to cm/yr by multiplying your average by 100,000.

f. Fill out the second table on your Data Worksheet to determine how far the Pacific Plate has moved in your lifetime. Which member of your group guessed the closest?

Hawaiian Island Map[8]

[8] Photo: NOAA, http://www.noaanews.noaa.gov/stories2008/20080116_hawaiicoral.html

Data Worksheet

Data Table One:

Island	Distance on map (cm or in)	Convert Distance to km	Age	Rate(Distance/Age)
Molokai			1.8 million years	
Oahu			3.3 million years	
Kauai			5.6 million years	
		AVERAGE		

1. Fill out the table below to determine how far the Pacific Plate has moved in the lifetime of the average student in your group.

2. How far is your answer in feet? There are 0.0328 feet in one centimeter.

3. How close was your guess?

Data Table Two:

Average rate (cm/yr)	Time (yr)	Distance (Rate * Time)
	17	

Tips for the Bowl - Plate Tectonics

Know your layers!
Inner core: solid core about 733 miles in diameter; made mostly of iron crystals

Outer core: same elements as inner core, but liquid because it is under less pressure; about 1410 miles thick

Mantle: mostly silicon and oxygen with some iron and magnesium; made of hot, dense magma (molten rock); thick and fluid-like; about 1800 miles thick

Crust: mainly oxygen, silicon, magnesium and iron; rigid solid layer; on average 5 miles (oceanic) to 25 miles (continental) thick

Know your plates![9]

Property	**Oceanic Crust**	**Continental Crust**
Age	About 70 to 180 million years old	About 3 billion years old
Thickness	4-7 miles	20-25 miles
Density	$3 g/cm^3$	$2.7 g/cm^3$
Composition	Mostly basalt, which has a dark, fine and gritty volcanic structure. It is formed out of liquid lava that quickly cooled.	Mostly igneous rocks. The upper part is mostly granite rocks, while the lower part consists of basalt and diorite. Granite is lightly-colored, coarse-grain, magma.

Know your geological terms!
Lava: molten rock that has exited through an opening in the Earth's crust

Igneous rock: rock solidified from cooled magma or lava at or below the surface of the Earth

Erosion: the process that carries weathered rock, soil and organic material from one place to another, for example through wind, water and glacial movement

Sediment: accumulated organic and inorganic particles

[9] National Marine Educators Association. 2010. *Life on an Ocean Planet*. Current Publishing Corps, Santa Margarita, CA. 598pp.

Plate Tectonics I

1. The lithosphere is composed of which of the following:
    w. **Upper mantle and crust**
    x. Crust only
    y. Upper mantle only
    z. All layers of Earth except for the inner core

2. Reminder question: A CTD measures which of the following:
    w. Connectivity, Temperature, Depth
    x. **Conductivity, Temperature, Depth**
    y. Conductivity, Temperature, Density
    z. Currents, Temperature, Depth

3. Which of the following is true of oceanic plates compared to continental plates?
    w. Oceanic plates tend to be much older
    x. Oceanic plates tend to much thicker
    y. Oceanic plates are composed of mostly the same type of material
    z. **Oceanic plates are typically denser**

4. About what age is the oldest oceanic crust?
    w. Around 20 million years old
    x. **Around 180 million years old**
    y. Around 300 million years old
    z. Around 3 billion years old

5. Oceanic crust is primarily composed of this type of material:
    w. Granitic
    x. **Basaltic**
    y. Gold-based
    z. All of the above

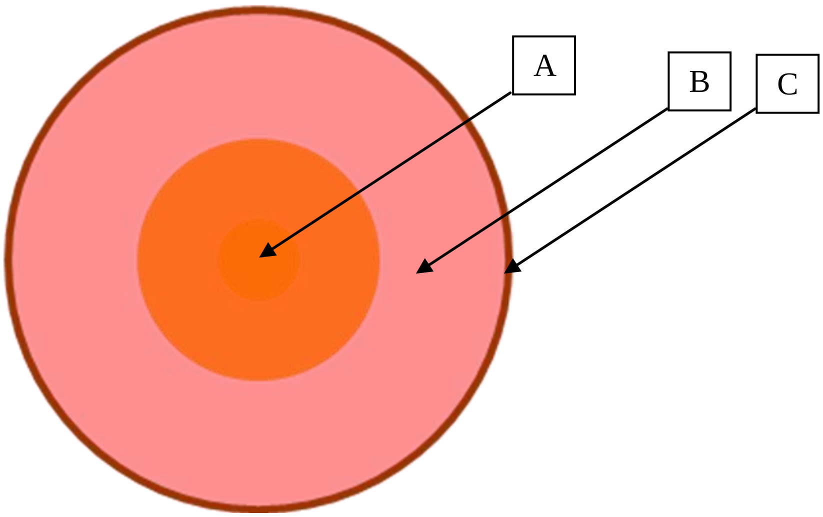
6. Of the following, which is the thinnest of Earth's layers?
    w. Mantle
    x. **Crust**
    y. Inner core
    z. Outer core

7. Short answer: What term refers to the weak, soft layer of solidified magma underneath the lithosphere?
    Answer: Asthenosphere

8. Short answer: Name the plate on which Washington, DC is located.
   Answer: North American Plate

9. Which of the following choices most accurately describes the lithosphere?
   w. **It is like a puzzle, composed of rigid pieces in constant motion**
   x. It is like a puzzle, composed of rigid pieces that do not move
   y. It is one continuous, rigid layer
   z. It is one continuous, soft liquid-like layer

10. Team Challenge Question

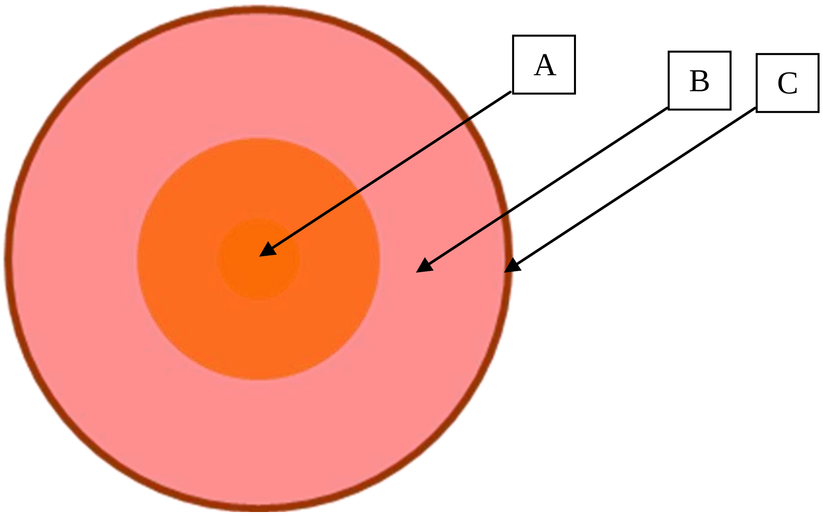


1. Identify Earth's layers labeled A-C in the cross-section above. (3pt)
   A.
   B.
   C.

2. What are the two types of crustal plates? (2pt)

3. Distinguish the lithosphere from the asthenosphere. (2pt)

ANSWER



1. Identify Earth's layers labeled A-C in the cross-section shown above. (3pt)
   A. **Core (1pt)**
   B. **Mantle (1pt)**
   C. **Crust (1pt)**

2. What are the two types of crustal plates? (2pt)
   Oceanic and continental (1pt each)

3. Distinguish the lithosphere from the asthenosphere. (2pt)
   The lithosphere is the rigid layer composed of the top of the upper mantle and the crust (1pt) and the asthenosphere is the underlying fluid layer composed of slowly moving magma (1pt).