DRAFT (JAN 2014)

How Old Is the Ocean Floor? Discoveries from Scientific Ocean Drilling

Summary

These lessons help students explore the relative ages of the rocks and sediments of the ocean and continents. Observations and conclusions based on scientific ocean drilling are combined with GeoMapApp, a powerful visualization tool, allow students to explore the age of rocks exposed in global ocean basins. With this tool, students will be able to understand patterns that support the important geologic theory of Plate Tectonics. Comparing age of rocks at the student's location to ocean crust can be made.

The lessons begin by providing necessary background information about methods used to determine the age of materials brought to the surface using technology aboard the *JOIDES Resolution* drilling ship. Students use GeoMapApp (a free program developed at the Lamont-Doherty Earth Observatory of Columbia University) to study color-coded patterns based on sea floor ages. Detailed data selected from specific drilling locations are presented. The lessons conclude with the opportunity to compare the age of ocean floor with bedrock in the student's home locality.

Learning Objectives

Students will be able to:

- Use GeoMapApp data sets and other resources to explore the relative ages of representative locations on the ocean floor;
- Discover relationships between sea floor ages and tectonic plate boundaries, especially spreading centers and subduction zones;
- Compare the ages of rocks in their home locality with rocks on the ocean bottom; and
- Summarize what they learn through grade-appropriate responses and essays

Standards (just listing the categories)

- **NGSS**:
  ESS1-c, ESS1-i, ESS1-h, ESS2-c, ESS2-a, ESS-2b, ESS-2e, PS1.C
- **NRC Framework**:
  Analyzing and Interpreting Data, and Constructing Explanations and Designing Solutions
- **CrossCutting Concepts:**
  Patterns; Scale Proportion and Quantity; Stability and Change; Interdependence of Science, Engineering and Technology
- **Ocean Literacy Essential Principles:**
  Principles 1, 2, 7
- **Earth Science Literacy Big Ideas:**
  Ideas 1, 3, 4, 5

Target Grade 9th-12th Grade and College, may be adapted for middle level

Background Information Students must have prior knowledge of Earth Science processes including rock types, Plate Tectonics, Mid-Ocean Ridge formations, stratigraphy; math concepts in reading and creating graphs, including color-coded charts; and reading skills, including the ability to follow directions for using web-based resources.

Materials Needed

- Internet access able to download and operate GeoMapApp (www.geomapapp.org)
- OR download EarthObserver from the iTunes store: https://itunes.apple.com/us/app/earthobserver/id405514799?mt=8#
- A world map with oceans labelled

Introduction

"As old as the hills" is an expression that something has been around for a very long time. But geologists want to know more. Just how old are "the hills" or other parts of the Earth? What does it tell us about Earth's geologic history if all continents and oceans are the same age or if parts of the land and sea differ in age?

The activities presented in this lesson use scientific and educational resources based on ocean drilling to investigate important questions such as:

- How can we determine the age of rocks and sediments that make up seafloors?
- Where are the oldest parts of the oceans?
- Do the Pacific, Atlantic, Indian, and Arctic ocean basins have the same age and patterns?
- How does the age of the ocean floor compare with the age of rocks on the continents?

In 1968, scientists aboard the first scientific ocean drilling ship *Glomar Challenger* brought up **cores** from the sea floor in the South Atlantic. The age of the rocks and sediment in the cores were determined using a variety of techniques. (**Note**: Appendix 1 provides links to related lessons available through the Deep Earth Academy's educational resources.) Study of these initial ocean bottom cores provided evidence that oceanic crust is not all the same age, but becomes progressively older in symmetrical patterns on either side of the **Mid-Atlantic Ridge**. This evidence supported the then-controversial idea of **seafloor spreading**.

Additional Resource for Teachers:

- What Is a Core?
- How Old is It? – Magnetostratigraphy (Paleomagnetism) and the Geomagnetic Polarity Timescale.

Over the decades since these first discoveries, scientific ocean drilling has been conducted at hundreds of locations. Together, with other **geochemical** and **geophysical** research methods, scientists have created been able to make maps of the age of the oceans. Each new Expedition adds to our knowledge about Earth processes—past, present and future—and enables us to understand the oceanic crust at a higher resolution.

Note to Teacher: You may choose to use this pre/post-test for assessing the lesson.

Before beginning this lesson, take this pre-test and then compare your answers with what you find out during these activities.

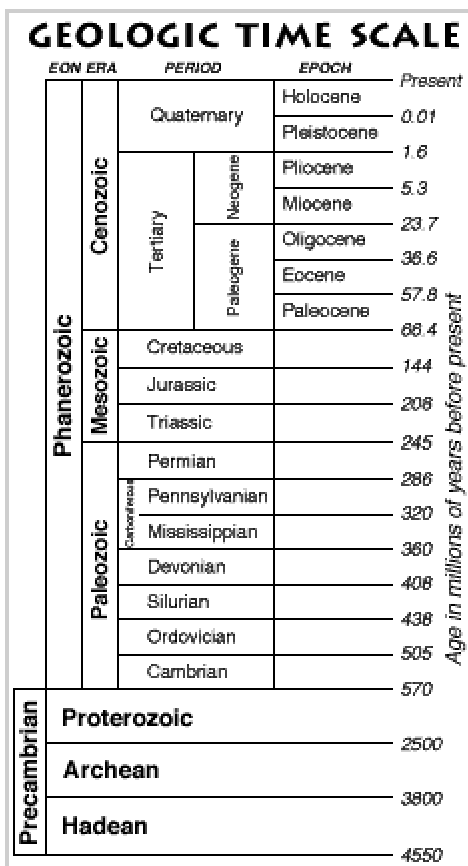
- In general, which is older, the ocean floors or continents?
- What methods are used to determine the age of rocks and sediments on the ocean floor?
- Do all ocean regions have the same age and patterns? Please provide examples.
- How old are the oldest parts of the oceans and where are they? The youngest?

How Can We Determine the Age of Oceanic Crust?

For more than 200 years, geologists have developed a range of methods to determine the age of rocks and fossils on the continents. At first, they used fossils to determine **relative ages**—that is, whether fossils in one layer were older or younger than other fossils based on the layer in which the fossils were found. In an undisturbed setting, the oldest layer is on the bottom.

The discovery of radioactive isotopes enabled scientists to determine more accurately the **absolute age** of rocks and fossils. Some were found to be thousands, millions, or even billions of years old. Scientists combined their findings to describe geologic formations and events from Earth's history with geologic time scales. These are like calendars that divide Earth's past into eons, eras, periods, and epochs.

One possible version includes the image below:



(Source: http://www.nature.nps.gov/geology/usgsnps/gtime/geoltimebw.gif)

When the *JOIDES Resolution* or other scientific drilling vessels bring up a core from the ocean floor, scientists and technicians collect samples from the sediments or rocks to determine their age. Determining absolute age can be accomplished using several techniques.

One technique called **biostratigraphy**, involves identifying **microfossils** in the sediments. **Micropaleontologists** have learned that different species of **foraminifera**, **diatoms**, and other microscopic plankton lived at different times and environments. By identifying the species found in a layer, an absolute age can be inferred.

Additional Resource for Teachers:

- "How Old Is It? Part 1 -- Biostratigraphy

Another age-dating method makes use of **paleomagnetism**, which is the study of how iron-rich minerals - such as magnetite - preserve Earth's magnetic orientation. The orientation of Earth's magnetic field has varied over geologic time. When rocks in the crust form, the direction of the magnetic field is recorded. Scientists use paleomagnetism to develop magnetic time scales that indicate when changes in the Earth's magnetic field occurred. They infer the age of oceanic crust collected in cores by matching the sequence of magnetic patterns in the core to the known sequence of changes in the geologic time scale.

Additional Resource for Teachers:

- How Old is It? – Magnetostratigraphy (Paleomagnetism) and the Geomagnetic Polarity Timescale.
- Nannofossils Reveal Seafloor Spreading Truth

A third type of absolute age dating uses **radioactive** elements within minerals found in both sediments and rocks. This technique is based upon established principles of atomic decay patterns. **Geochemists** measure the concentrations of radioactive **isotopes** and their **decay products** in minerals to find the time when the mineral - and thus the rock - formed. Biostratigraphic and paleomagnetic ages have been calibrated using radiometric ages.

Each of these methods can be used to cross-check the age of a sample so as to ensure accuracy of the dating process. However, all methods contain some **measurement uncertainty**. Ages are often stated as a time range. The age of a rock or fossil could be given as 36 million years ago +/- 2 million years. This indicates the sample could be as old as 38 million or as young as 34 million years old.

ACTIVITY 1: What Age Patterns Are Observed in the Ocean Floor?

A map of ocean floor age is provided through **GeoMapApp.** This is an interactive exploration and visualization application created by the Marine Geoscience Data System of the Lamont-Doherty Earth Observatory of Columbia University. Tutorials are available for GeoMapApp here: http://www.youtube.com/user/GeoMapApp.

1. Open GeoMapApp at www.geomapapp.org. Follow the prompts to download the appropriate version for your computer. The application opens to a map of the world illustrating topography.

   On the top menu bar, select Basemaps → Global Grids → Seafloor Bedrock Age.

   The map uses a color-coded system and lines that divide the ocean floor into different ages. These lines are called **isochrons** - from Greek words, "iso-" meaning "same" and "-chron" meaning time. Note that dividing lines may not be in the exact place where rocks of that age occur, but the pattern gives a good idea of relative age.

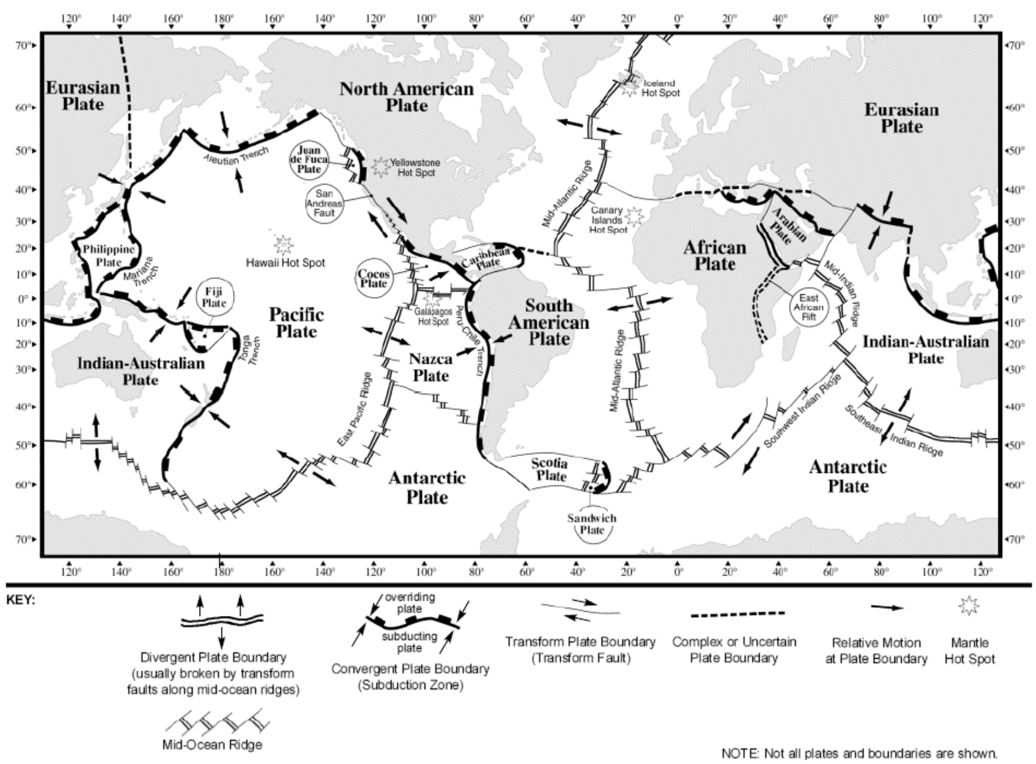
   Explore the data by moving your mouse over the image. On the top bar, numbers indicate latitude, longitude, and the age of the rocks at each location of your mouse (denoted with mY; meaning millions of years). Slowly move your mouse across the oceans horizontally (same latitude), vertically (same longitude), or diagonally, and watch how age changes are indicated. Use this map to answer the following questions.

Problem Set 1: Seafloor Crustal Age

NOTE: If you get stuck using GeoMapApp, it is easier to close and restart it.

1. What colors represent ocean bottom with the youngest ages?

2. Look at a world tectonic map, such as Fig. 2. What type of plate boundary or ocean floor feature occurs where these young rocks are shown?



[Source: http://www.p12.nysed.gov/assessment/reftable/earthscience-rt/esrt2011-engr.pdf]

3. What colors represent the oldest sea floor rocks?

4. Where are these found? What ocean floor features occur there?

5. Describe the age patterns you observe in the Atlantic Ocean.

6. Describe the age pattern you observe in the Indian Ocean.

7. Describe the age pattern you observe in the Pacific Ocean.

8. Earthquakes often occur at plate boundaries. On the menu bar at the top, select Portals → Earthquake Locations, Epicenter Depths, and Magnitudes. After this layer loads, compare the locations of earthquakes with the age of the sea floor.

9. Do earthquakes occur where the oceans are older or younger in the Atlantic Ocean? What about in the Indian Ocean?

10. As you move your cursor over the Mid-Atlantic Ridge and Mid-Indian Ridge, do you notice a symmetry in age on both sides? Explain how this supports the theory of divergent

crustal plates.

11. Move your cursor over the East Pacific Rise. How does the age pattern here compare with that of the Mid-Atlantic Ridge and the Indian Ocean Ridge?

12. Move your cursor over the earthquake zones in the western Pacific Ocean. What differences do you notice in the age of the seafloor on each side of the Aleutian Trench, Mariana Trench, and Tonga Trench? Explain how this supports the concept of convergent boundaries as related to plate tectonics.

ACTIVITY 2: How Does Seafloor Age Vary at Ocean Drilling Locations?

1. Open the Layer Manager by clicking the last button on the menu bar clicking off the earthquake data set. Click on Portals → Ocean Floor Drilling.

   This will add a data layer illustrating the location where scientific drilling has occurred. It also displays a table about each drilling site. The age at each location is in the column labeled Crustal Age in millions of years (denoted as Ma).

2. Use your mouse to zoom in and out, move over the dots and use the Arrow icon to select a location.

3. To return to the global map, click Bookmarks on the top menu bar and select Zoom to Global Scale.

Problem Set 2: Exploring Sea Floor Age at Selected Ocean Drilling Sites

1. Use the ocean drilling map and data table below to record information about different parts of the ocean floor. There are two rows for locations of your choosing.

   For each location, record the:

   ID – This gives the Leg or Expedition of the drilling program and the site number. For instance, 13-134 means it was cored in Leg 13 and was the 134 site drilled.
   lat – This is the latitude. Positive numbers are in the Northern Hemisphere and negative numbers are in the Southern Hemisphere
   lon – This is the longitude. Positive numbers are in the Eastern Hemisphere and

negative numbers are in the Western Hemisphere.
crustal age – This is the age of the oceanic crust, in millions of years.
seafloor (m) – This is depth to the seafloor in meters.
Notes – Write additional information about the rocks and sediments.

Ocean Region	ID	lat(itude)	lon(gitude)	crustal age	seafloor (m)	Notes
Mid-Atlantic Ridge						
Atlantic Ocean floor east of Florida						
East Pacific Rise						
Pacific Ocean near the Mariana Trench						
Mid-Indian Ridge						
(Location of your choice)						
(Location of your choice)						

Activity 3: How Old Are the Rocks in Your Hometown?

You are going to explore how the age of oceanic crust compares with the age of bedrock in your local area.

Geologists use color-coded **geologic maps** to represent the age of rocks. The United States Geological Survey (USGS) is developing the National Geologic Map Database. Most states also have a geological survey with online resources.

Problem Set 3: Examine a geologic map of your state to answer these questions:

1. How old are the rocks where you live? Give both the geologic period and the approximate age in millions of years (Ma). Provide credit for the source of your information.

2. Describe the age of the bedrock where you live compared with the age of oldest and youngest seafloor rocks and sediments.

3. Briefly describe the range in age of the bedrock in your state, meaning the difference between oldest and youngest rocks.

4. Compare this age range in your state with age range of oceanic crust.

Additional Resource for Teachers:

GeoMapApp provides "Education Links" where you can learn more about earth systems. Two related learning activities are:

- Seafloor Spreading
  http://serc.carleton.edu/geomapapp/activities/seafloor_spreading.html
- Hawaiian Islands: Volcano Ages, Hot Spots, and Plate Motions
  http://serc.carleton.edu/geomapapp/activities/Hawaii_hotspot.html

Writing Across the Curriculum

1. Describe three important scientific ideas you learned through these activities?

2. Imagine you are writing a message to your Congressional Representative or Senator to explain the importance of funding scientific ocean drilling. What are two essential points that should be included?

3. If you could sail as a scientist or technician aboard the *JOIDES Resolution*, which method would you use to find the age of the sediments and rocks in cores? Explain why you chose this method.

Acknowledgements:

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Dr. Trevor Williams (Borehole Research Group, Lamont-Doherty Earth Observatory of

Columbia University); Dr. Andrew Goodwillie (GeoMapApp); Rose Sanders, Renee Aubry, and Magali Dupuy (Earth2Class Workshops for Teachers at Lamont-Doherty participants).

Resources Cited:

GeoMapApp: http://www.geomapapp.org

JOIDES Resolution website http://joidesresolution.org

"Nannofossils Reveal Seafloor Spreading Truth" http://www.oceanleadership.org/wp-content/uploads/2009/08/Nannofossils.pdf

NGDC "Age of the Ocean Floor Poster"
http://www.ngdc.noaa.gov/mgg/image/images/g01167-pos-a0001.pdf
Higher-resolution image: http://www.ngdc.noaa.gov/mgg/image/crustageposter.gif

GeoMapApp Learning Activity: Hawaii Volcano Ages, Hot Spots and Plate Tectonics
http://serc.carleton.edu/geomapapp/activities/Hawaii_hotspot.html

GeoMapApp Learning Activity: Seafloor Spreading
http://serc.carleton.edu/geomapapp/activities/seafloor_spreading.html

"What Is a Core?" http://www.oceanleadership.org/wp-content/uploads/2010/01/309WhatIsACore.pdf

"How Old Is It? – Part 1. Biostratigraphy" http://www.oceanleadership.org/education/deep-earth-academy/educators/classroom-activities/undergraduate/how-old-is-it-part-1-biostratigraphy/

"How Old Is It? Part 2 - Magnetostratigraphy (Paleomagnetism) and the Geomagnetic Polarity Timescale" http://www.oceanleadership.org/education/deep-earth-academy/educators/classroom-activities/undergraduate/how-old-is-it-part-1-biostratigraphy/

National Geologic Map Database http://ngmdb.usgs.gov/ngmdb/ngmdb_home.html

"Geologic Maps of the 50 United States" http://geology.about.com/od/maps/ig/stategeomaps/

Hawaiian Island: Volcano Ages, Hot Spots, and Plate Motions
http://serc.carleton.edu/geomapapp/activities/Hawaii_hotspot.html

Seafloor Spreading
http://serc.carleton.edu/geomapapp/activities/seafloor_spreading.html

USGS Geologic Timescale
http://www.geosociety.org/science/timescale/2012timescl-550.gif

Lesson Vocabulary
Add new terms as needed

Absolute age	Microfossils
Biostratigraphy	Micropaleontologists
Core	Mid-Atlantic Ridge
Decay products	Nannofossils
Diatoms	Paleontology
Foraminifera	Paleomagnetism
Geochemical/Geochemist	Plate boundary
Geophysical	Radioactive
Geologic maps	Radioactive decay products
Geologic time scales	Relative age
Glomar Challenger	Scientific ocean drilling
Isochrons	Seafloor spreading
Isotopes	
JOIDES Resolution	
Measurement uncertainty	