

# **GEO/OC 103**

## **Exploring the Deep...**

### **Lab 2**

### Reading 1.3

# Ocean origins

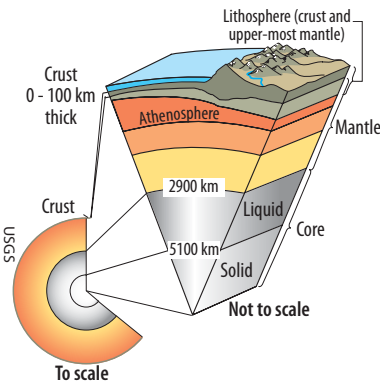
## How did the oceans form?

**density** — the ratio of mass to volume of an object or substance. Mathematically,

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

**plastic** (adjective) — able to change shape without breaking.

**volatile** (adjective) — easily evaporated.



**Figure 1.** Earth’s internal structure is defined by differences in density, composition, and the physical state of the material.

Scientists believe that the oceans developed early in Earth’s history—at least 3.8 billion years ago. When our planet formed 4.6 billion years ago, heat from compression, nuclear reactions, and collisions with solar system debris caused the early Earth to melt. Molten materials separate, or differentiate, into layers based on **density**. In Earth, this process formed concentric layers, beginning with a dense iron-nickel core, surrounded by a thick mantle made of magnesium, iron, silicon, and calcium (Figure 1 at left). The rock with the lowest density rose to the surface to form a thin crust. Together, the crust and rigid part of the upper mantle form the **lithosphere**, with an average thickness of around 100 km. Beneath the lithosphere is the **asthenosphere**, a ductile or **plastic** region of the upper mantle.

During differentiation, **volatile** elements trapped within the early Earth rose towards the surface and were vented by volcanoes to form our atmosphere. This early atmosphere consisted mainly of hydrogen and helium, very light elements that were easily lost to space. Around 3.9 billion years ago, as Earth condensed further, a second atmosphere formed, but it contained only traces of free oxygen (O<sub>2</sub>). This early atmosphere reflected much of the solar radiation striking Earth, allowing the surface to cool and water vapor to condense into rain. At first, Earth’s surface was too hot for liquid water to exist on the surface. Eventually, it cooled enough for water to accumulate, forming the early oceans. Scientists think that this is when the crust began to differentiate into two types—continental and oceanic crust—because the process that forms granite, the most common type of continental rock, requires the presence of water.

The earliest forms of life—blue-green algae—developed in the oceans, where water offered protection from the harmful ultraviolet (UV) radiation that penetrated Earth’s early atmosphere. Through the process of photosynthesis, these organisms produced their own food using carbon dioxide, water, and energy from the sun, and released an important by-product—oxygen.

1. Why were there no oceans during the first 800 million years of Earth’s history?

2. Why do scientists think that the continental rocks could not have formed before the oceans?

## Why are the ocean basins so much younger than the continents?

To understand the answer to this question, you must examine the processes that form and modify oceanic and continental lithosphere.

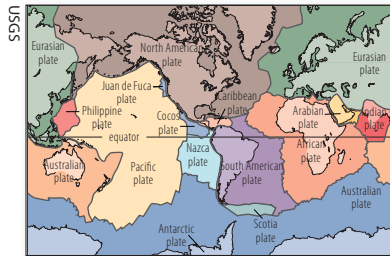


Figure 2. Earth's major lithospheric plates.

### Plate tectonics

Earth's outermost layer, the **lithosphere**, is made up of the crust and uppermost part of the mantle. The theory of **plate tectonics** states that the lithosphere is fragmented into 20 or so rigid plates that are moving relative to one another (Figure 2 at left). The plates move atop the more mobile, plastic asthenosphere.

Earth's core reaches temperatures over 6000 °C. About half of this heat comes from the decay of naturally occurring radioactive minerals. The rest is left over from the heat generated when Earth formed. Heat energy travels slowly from Earth's interior to the surface by the processes of **conduction** and **convection**.

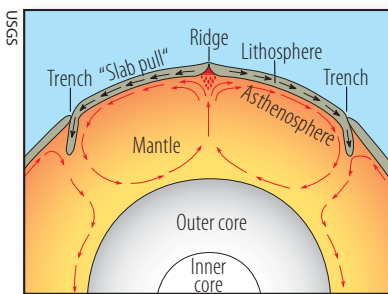


Figure 3. Convection in Earth's mantle transports heat energy to the surface.

In conduction, heat energy moves by collisions between molecules. Convection occurs as rock heats up, expands, becomes less dense, and rises toward the surface (Figure 3 at left). Near the surface it cools, contracts, becomes denser, and slowly sinks deep into the mantle again. Convection cools Earth more efficiently than does conduction. Still, it takes a long time—billions of years—to cool an object the size of Earth. As long as sufficient heat reaches the upper mantle, Earth's lithospheric plates will continue to move.

### Types of plate boundaries

There are three types of plate boundaries, classified according to how adjacent plates are moving relative to each other (Figure 4 on the following page).

At **divergent boundaries**, plates move away from each other, forming rift valleys on land and spreading ridges in the oceans. These mid-ocean ridges form the longest mountain belt on Earth, extending over 60,000 km on the ocean floor. At the ridge, molten rock or magma wells up between separating plates and intrudes into the plates, solidifying into new oceanic crust along the ridge crest. Pressure from beneath the ridge, combined with gravity, causes the plates to continually break during earthquakes and spread apart, allowing more magma to rise to the surface, creating more new crust. As the new crust moves away from the ridge, it cools and contracts, becoming denser. Over time, the upper mantle beneath this crust cools, thickening the lithosphere. As the density of the crust and lithosphere increase, they sink deeper into the mantle and the ocean basin deepens. The high ridge at the plate boundary is stationary while the plates themselves move away, revealing their generally flat topography.

At **convergent boundaries**, the plates are moving toward each other (Figure 4). If the two plates are topped with continental crust, they will collide, causing the crust to pile up and create mountains. If one or both plates are composed of only oceanic lithosphere, the older denser oceanic plate will plunge down into the mantle, in a process called **subduction**. Both plates are bent downward along their line of contact, forming a deep trench at the surface along the plate boundary.

The subducting oceanic plate carries with it sediments and water from the surface. Near a depth of 150 km, the descending plate heats up sufficiently for some of the material to melt. The water and sediments change the chemistry of the **magma**

Plate boundary animations

To see animations and visuals of the plate boundaries, launch ArcMap, locate and open the etoe\_unit\_1.mxd project file, then open any data frame. Click the Media Viewer button and choose any of the following movies or visuals from the media list.

- Ridge Spreading and Subduction
- Transform Boundary
- Ocean-Continent Convergent Boundary
- Continent-Continent Convergent Boundary
- Divergent Boundary

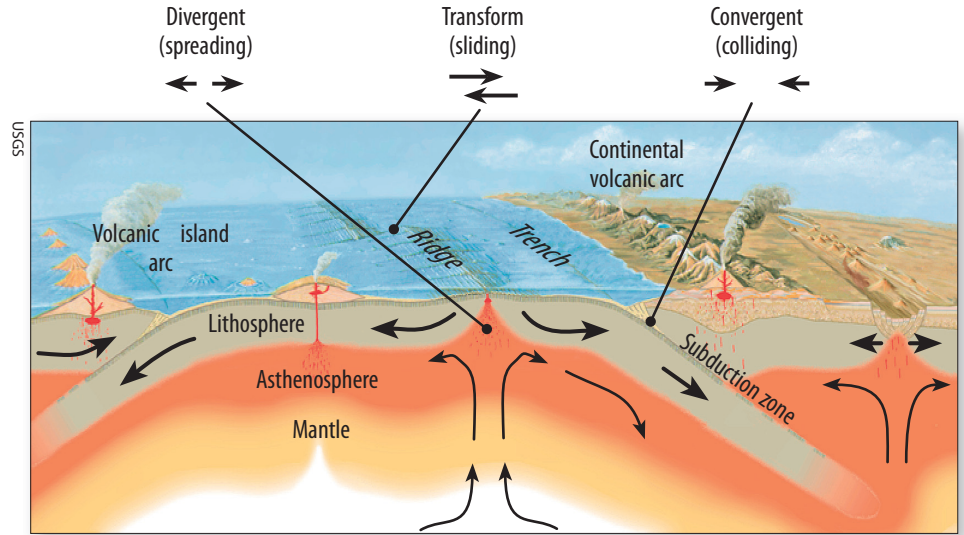


Figure 4. Types of plate boundaries.

(molten rock within the Earth), that rises toward the surface and cools to form new continental rock.

At **transform boundaries**, plates move past each other (Figure 4). The most famous transform boundary in North America is the San Andreas fault in California. Smaller transform faults accommodate movement along spreading ridges, allowing segments of the ridge to expand independently. These types of boundaries and faults are characterized by frequent earthquakes. Transform boundaries are important in rearranging the plates, but are not directly involved in creating or recycling crustal rock.

Tectonic plates have been created, destroyed, and rearranged countless times over Earth’s 4.6 billion-year history. New ocean floor forms at mid-ocean ridges, and old ocean floor is recycled into the mantle at trenches. Gravity will not allow Earth to expand or shrink, so the net amount of new rock formed must balance the amount being recycled. Because the oldest oceanic crust can be dated to about 190 Ma, it is reasonable to say that the entire ocean floor, covering some 70 percent of Earth’s surface, is completely recycled every 190 million years at the current rates of motion.

On the other hand, the low-density continental rock remains on the surface and is not recycled except through **weathering** and **erosion**. In fact, continental rocks that formed 3.8 billion years ago can still be found on Earth’s surface today, along with continental rock that formed more recently. Thus, plate tectonics and density differences between continental and oceanic rocks explain why the ocean basins are much younger than the continents.

**weathering** — the physical disintegration and chemical altering of rocks and minerals at or near Earth’s surface.

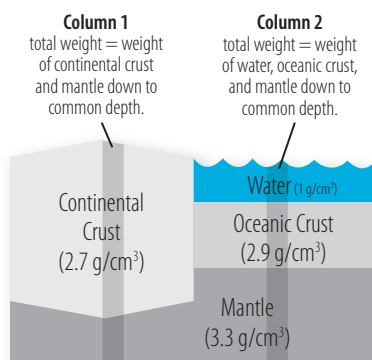
**erosion** — the process by which Earth materials are worn away or removed from their source area by wind, water, or glacial ice.

3. If new ocean crust is formed at mid-ocean ridges, where would you expect the oldest ocean floor to be found?

4. At which type of plate boundary does each of the following types of crust form?
- Oceanic —
  - Continental —

## Why are the ocean basins so much lower in elevation than the continents?

**igneous rock** — rock formed by the cooling and crystallization of magma or lava.



**Figure 5.** The principle of isostasy. Columns with the same area and to the same depth have equal weight.


**equilibrium** — state of balance; condition where no overall changes occur in a system.

### Exploring isostasy

To explore the principle of isostasy, point your Web browser to:

[atlas.geo.cornell.edu/education/student/isostasy.html](https://atlas.geo.cornell.edu/education/student/isostasy.html)

You can also:

- Open the **etoe\_unit\_1.mxd** project file.
- Open any data frame.
- Click the Media Viewer button .
- Choose **Explore Isostasy**.

Earth's surface has two main features: deep ocean basins and elevated continents. This uneven distribution of topography is no coincidence—it occurs because of gravity and the fact that the continental and oceanic crusts are made of different types of rock and have different thicknesses and densities.

The ocean floor is primarily composed of **basalt** (buh-SALT) and **gabbro** (GAB-bro), dark-colored **igneous rocks** with the same composition and density (~2.9 g/cm<sup>3</sup>), but which form in different environments. Basalt comes from magma that erupts *onto* the ocean floor, whereas gabbro crystallizes from magma that cools *within* the oceanic crust. Oceanic crust averages around 6 km thick, except at oceanic plateaus, where it may reach a thickness of up to 40 km.

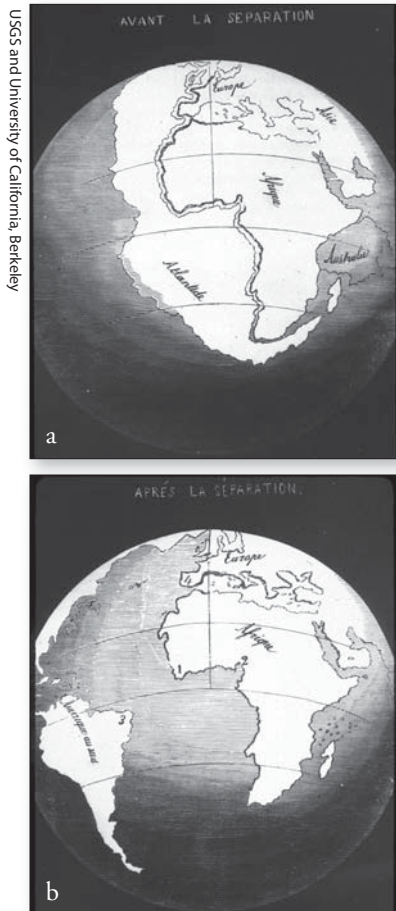
The continents are composed primarily of **granite**, a light-colored igneous rock with a density of around 2.7 g/cm<sup>3</sup>. Continental crust averages about 40 km thick, varying from as little as 20 km to as much as 70 km at high-elevation continental plateaus such as the Tibetan Plateau (the Himalayas).

The existence of deep ocean basins and high-elevation continents is due to the principle of **isostasy** (eye-SAHS-tuh-see), which states that *the total weight of any column of rock and water from Earth's surface to a constant depth is approximately the same as the weight of any other column of equal area from its surface to the same depth* (Figure 5 at left). Differences in the heights of the columns are due to differences in the density and thickness of the materials in the columns. The **equilibrium** between columns is maintained by the plastic flow of material within Earth's mantle. Though rock in the mantle is generally not hot enough to melt, it is warm enough to flow or change shape very slowly when subjected to a force, much like modeling clay or Silly Putty®.

In the simplest example, isostasy is the principle observed by Archimedes (ahr-kuh-MEED-eez) in the third century B.C., when he noticed that an object immersed in water displaces a volume of water equal to the volume of the object. When two columns of different depth and weight form on Earth's surface, the mantle will slowly flow out from beneath the added load. The region with greater weight will have less mantle beneath it than the region with lesser weight.

If crust or water is removed from the top of the column, mantle material flows in underneath the column to compensate for the reduced weight, pushing the column back up slightly. On the other hand, if more crust or water is piled atop the column, mantle material flows away from the bottom of the column to equalize the weight, causing the column to sink back down slightly. The mantle behaves in a manner similar to that of water when an ice cube is placed in a container of water. Water beneath the ice flows outward and upward and the ice sinks downward until the water and ice reach equilibrium.

- If a 1-km thick layer of material were removed from the top of a continent by erosion, would the elevation of the continent decrease by 1 km? Explain.

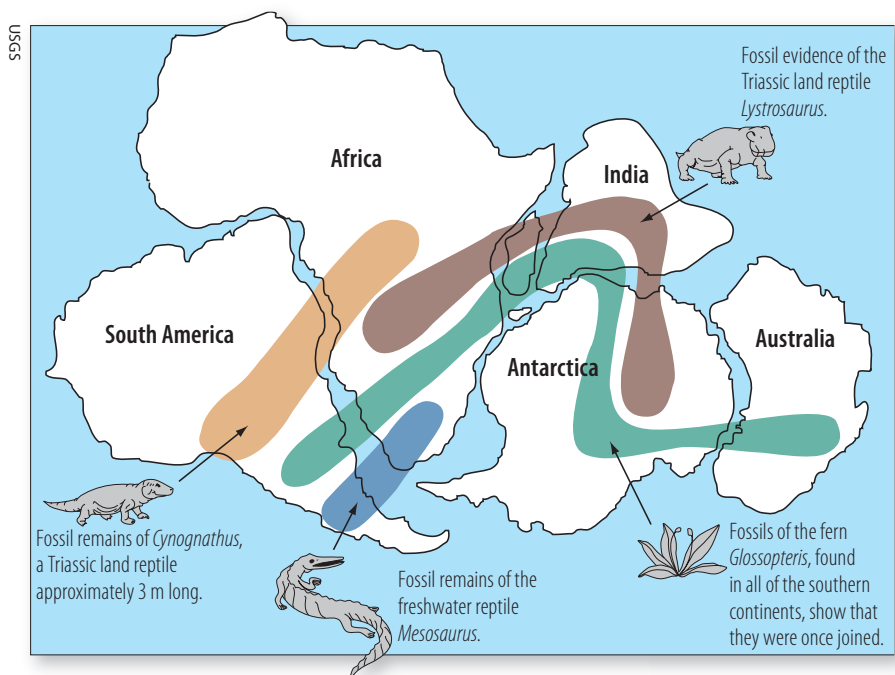


**Figure 6.** In 1858, geographer Antonio Snider-Pellegrini noted how the American and African continents may once have fit together (a), then later separated (b). In the early 1900s, German climatologist Alfred Wegener expanded on this idea in his theory of *continental drift*.

## How do we know what the continents and oceans looked like in the past?

Over the past 200 years, scientists have collected evidence of Earth’s changing surface through mapping and monitoring topography; studying earthquakes, volcanoes, and fossils; and measuring the ages of rocks.

As early as the 1600s, cartographers noticed that the coastlines of continents sometimes appeared to match up, even across oceans, like pieces of a puzzle (Figure 6 at left). Then, in the 1800s, scientists discovered that continents separated by vast oceans contained similar landforms, rocks, and fossils. This discovery suggested that today’s continents are in very different places than they were in the past (Figure 7 below). The theory that the continents moved over time to their present locations is called **continental drift**. None of these observations provided an explanation for how entire continents could move over Earth’s surface, so the theory was not widely accepted. The key evidence for the mechanism driving plate tectonics came in the mid-1900s, through detailed studies of earthquakes, volcanoes, and the ocean floor.



**Figure 7.** Fossil evidence points to a time around 250 million years ago when the present-day continents shown above were joined in a larger continent, now called *Gondwanaland*.

## How old is that rock?

The ages of rocks are determined through a variety of methods. Some techniques allow us to rank the ages of rocks relative to one another, whereas others allow us to assign numerical ages to individual rocks.

### Relative dating

Relative dating methods do not tell us the actual ages of rocks, but they do allow us to determine the **chronological** (krah-nuh-LAH-ji-kuhl) sequence in which rocks formed. Using a series of **stratigraphic principles** (see sidebar), scientists can often reconstruct the history of a sequence of rock layers (**strata**) and geological events. Relative dating techniques are most useful on the continents, where rocks have been uplifted and exposed by weathering and erosion, or can be drilled into relatively easily.

**chronological** — arranged in order of time of occurrence.

### Stratigraphic principles

#### Original horizontality

Sedimentary layers and lava flows are originally deposited as relatively horizontal sheets called *strata* (singular: stratum).

#### Lateral continuity

Lava flows and sedimentary layers extend laterally in all directions until they thin to nothing or reach the edge of the basin of deposition.

#### Superposition

In undisturbed rock layers or lava flows, the oldest is at the bottom and the youngest is at the top.

#### Inclusions

A piece of rock included in another rock or layer must be older than the rock or layer in which it has been incorporated.

#### Cross-cutting

A feature that cuts across another feature must be younger than the feature that it cuts.

#### Unconformities

Surfaces called unconformities represent gaps in geologic time where layers were not deposited or have been removed by erosion.

#### Faunal (fossil) succession

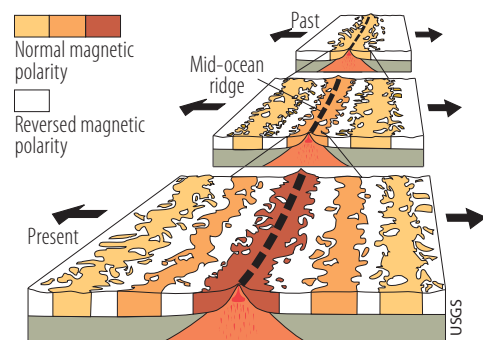
Plants and animals evolve over time, and each time period can be identified by a unique assemblage of plant and animal fossils.

### Absolute dating

Absolute dating techniques use laboratory analysis to determine how much time has passed since the rocks formed. Most igneous rocks — rocks that form from cooled magma or lava — contain tiny amounts of radioactive elements. These radioactive **parent** elements break down into different **daughter** elements over time at a known rate. By precisely measuring and comparing the amount of parent to daughter elements in a rock, a process called **radiometric dating**, scientists can determine how many years ago the rock formed. Absolute dating techniques are useful for both oceanic and continental rocks, but relatively few oceanic rocks have been dated radiometrically because obtaining good samples is difficult and costly. In practice, absolute and relative dating techniques are often used together to determine approximate ages of rocks.

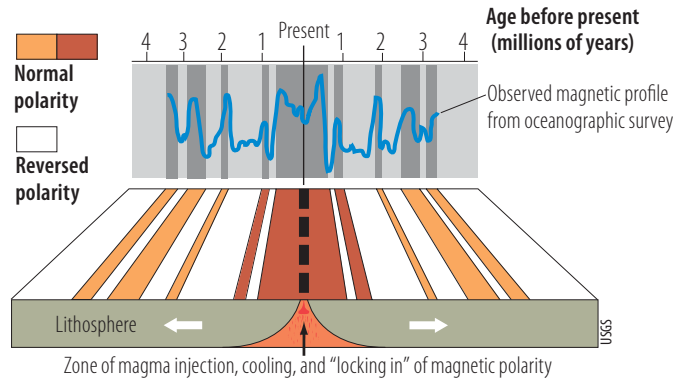
### Paleomagnetism

The ocean floor is composed primarily of an igneous rock called basalt that forms as magma erupts at or near Earth's surface and cools rapidly. Before the magma solidifies, some of the mineral grains turn like tiny compasses, preserving the direction of Earth's magnetic field. For reasons that are not fully understood, Earth's magnetic field periodically changes polarity. That is, the north and south magnetic poles reverse. This process occurs irregularly every tens of thousands to millions of years; and each time there is a reversal, minerals in the new rock align differently from those in the older rock next to it. Thus, reversals appear as bands of alternating polarity in the ocean floor. This phenomenon, called **paleomagnetism**, preserves a record of Earth's past magnetic fields. At oceanic spreading ridges, the bands appear as symmetrical patterns on either side of the ridge. Like the growth rings of trees, the unique patterns formed by these bands allow scientists to assign ages to the rocks (Figures 8 and 9).



**Figure 8.** As plates move apart, symmetrical patterns of normal and reversed polarity are preserved in the rocks.

Ships crisscross the oceans, recording these patterns with sensitive **magnetometers** — devices that



**Figure 9.** Magnetic polarity profiles are analyzed to determine the age of the ocean floor.

measure the strength and direction of the magnetic field preserved in oceanic rocks. These data confirm that new ocean floor forms at ridges and moves away from the ridge, providing additional confirmation of plate tectonic theory. In addition, researchers have used paleomagnetic data to measure the rate of ocean-floor spreading and to reconstruct the history of ocean basin development.

6. Briefly explain the advantages and disadvantages of the following dating techniques for dating ocean-floor rock.
  - a. Radiometric dating

- b. Paleomagnetic dating

In this reading, you have explored how heat and gravity drive the processes that are continuously changing Earth's surface. In the next two investigations, you will examine the ocean floor at increasing levels of detail to look for features that provide evidence of these processes.



## Investigation 1.5

# Ocean basin features

Early explorers learned (often the hard way) that the ocean floor is *not* smooth like a bathtub. But how does bathymetry vary among ocean basins or within a basin? And how is the shape of the basin related to the age of the rocks or the way the basin formed? To answer these questions, you will begin by looking at the general characteristics of each basin. Then you will examine, in detail, the floors of the ocean basins.

 Launch ArcMap, locate and open the **etoe\_unit\_1.mxd** file.


Refer to the tear-out Quick Reference Sheet located in the Introduction to this module for GIS definitions and instructions on how to perform tasks.


 In the Table of Contents, right-click the **Ocean-Floor Topography** data frame and choose Activate.

 Expand the **Ocean-Floor Topography** data frame.

 Turn on the **Ocean Basins** layer.

 Click the Identify tool .

 In the Identify Results window, select the **Ocean Basins** layer from the drop-down menu.

 Next, click within each ocean basin to obtain its average depth and surface area.

- Record the average depth and surface area of each ocean basin in Table 1. Round all values to the nearest 0.1 km.

**Table 1—Global ocean basin statistics**

Ocean	Average depth <i>km</i>	Depth rank	Surface area <i>million km<sup>2</sup></i>	Area rank
Arctic				
Atlantic				
Indian				
Pacific				
Southern				

- Rank the oceans by the amount of surface area and by depth using the numbers 1 through 5, with 1 being the largest or deepest and 5 being smallest or shallowest.
- Which ocean basin is the shallowest? How much shallower is this ocean basin than the next shallowest ocean basin?

 Close the Identify Results window.

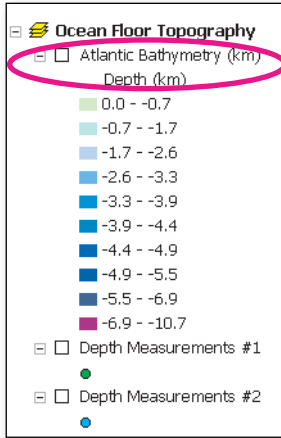


Figure 1. The new Atlantic Bathymetry layer produced by the quickload process will be located at the top of the Table of Contents.


Clearly, the Arctic Ocean is much shallower than the other oceans. Next, you will explore why.

- Turn on and expand all bathymetry layers: **Atlantic Bathymetry**, **Arctic Bathymetry**, **Indian Bathymetry**, **Pacific Bathymetry**, and **Southern Bathymetry**.

Unlike the other layers, the depth of the Atlantic Ocean is currently represented by a single shade of blue.

- Right-click the **Atlantic Bathymetry** layer and choose Remove.

You will now add a new **Atlantic Bathymetry** layer with the depth classified like the other bathymetry layers.

- Click the QuickLoad button .
- Select **Layers**, choose **Atlantic Bathymetry**, and click **OK**.
- Locate the new **Atlantic Bathymetry** layer in the Table of Contents (Figure 1).
- Click on the **Atlantic Bathymetry** layer and drag it down the Table of Contents so that it sits just above the **Pacific Bathymetry** layer.
- Turn on the **Atlantic Bathymetry** layer.

- Using the Bathymetry legends, list the color(s) and depth range of
  - the shallowest part of the ocean.

- the deepest part of the ocean.

- Turn on and expand the **Continental Shelf** layer.

This layer shows where continental rocks are submerged beneath ocean waters. This submerged land, called the *continental shelf*, extends as far as several hundred kilometers offshore and to a depth of about 200 m (Figure 2). Beyond the edge of the shelf, the steep *continental slope* drops away toward the *continental rise* and eventually the deep-ocean floor.

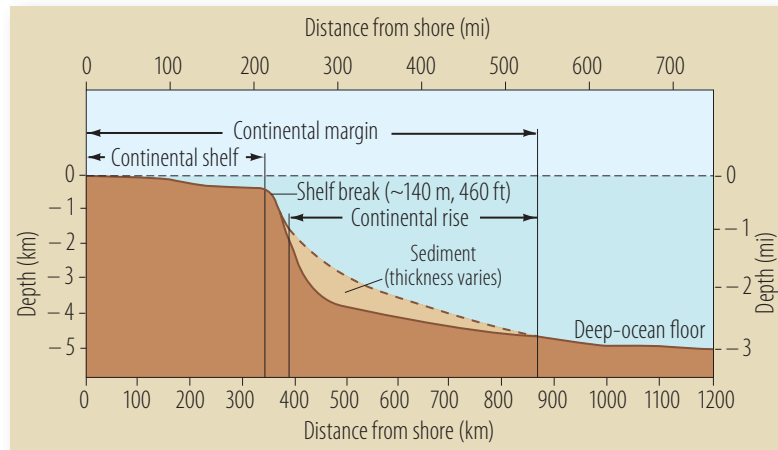


Figure 2. The continental margin.

- Which ocean has the greatest area of continental shelf?

The existence of the continental shelf is not the only reason for shallow ocean floors. Using depth as a guide, locate the submerged mountain range in the Atlantic Ocean basin.

- 6. Which of the other ocean basins contain similar submerged mountains?

 Turn off the **Continental Shelf** layer.

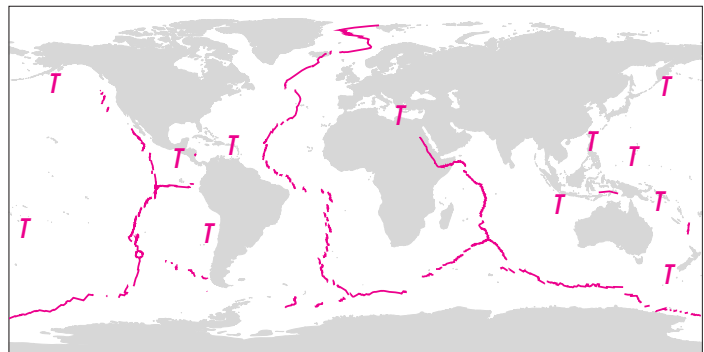
The submerged mountain range you discovered while examining the Atlantic Ocean bathymetry is the Mid-Atlantic Ridge, an example of a spreading ridge. The discovery of the Mid-Atlantic Ridge in the 1930s caused scientists to wonder about the processes that form this type of underwater ridge system and what other types of features may exist on the ocean floor.

 Turn on the **Ridges** layer.

This layer displays the locations of mid-ocean ridges.


- 7. On Map 1, see the locations of the oceanic spreading ridges. Turn off all of the layers but the **Ridges** and **Countries** layers to see the mid-ocean ridges more easily.

Map 1— Oceanic ridges and trenches



 Turn on and expand the **Ocean-Floor Age** layer.

- 8. Describe any patterns you observe between the location of the ridges and the age of the ocean-floor rocks.

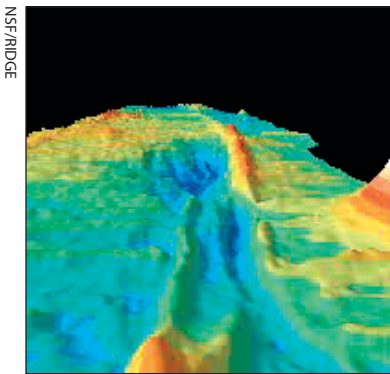
 Turn off and collapse the **Ocean-Floor Age** layer.

Next you will determine if there is a relationship between the age of the ocean floor and its depth. You will examine the rocks with ages between 0 and 120 million years.

- 9. Describe the relationship between ocean-floor age and depth indicated in Figure 3 on the following page.

### Ridge flyby animation

To view a simulated "flight" along a ridge, click the Media Viewer button  and choose **Mid-Ocean Ridge Flyby** from the media list.



### Why is the depth negative?

The elevation of a mountain like Mount Everest is based on measuring from sea level to the top of the mountain. In these materials, we will express the depth of a body of water from sea level downward, using negative values. Therefore, we will say the depth of the Mariana Trench is – 11,035 meters.

### What is Ma?

The Greek prefix *Mega* represents *one million* in the metric system. The Latin word for year is *annum*. As used in Earth science, Ma stands for *Mega annum*, or *millions of years before present*.

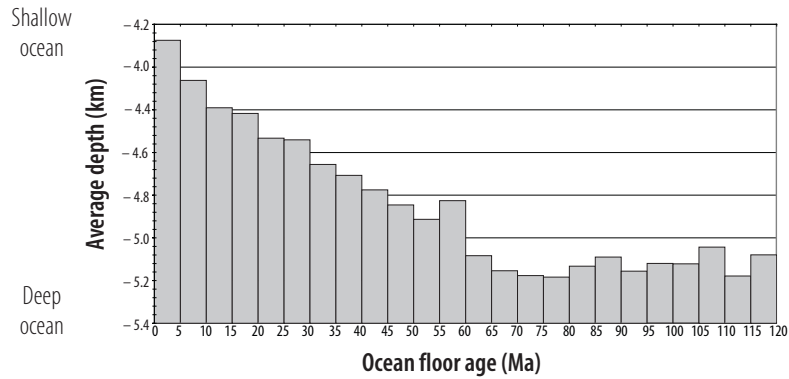


Figure 3. Average depth versus ocean-floor age.

To better understand the processes that form ridges, look at a block diagram of the Mid-Atlantic Ridge.

- Turn on and select the **Block Diagrams** layer.
- Using the Hyperlink tool , click on the profile line that crosses the Mid-Atlantic Ridge to view a block diagram of the ocean floor. (Hint: It is in the same location as the Atlantic Crossing line. Move the Hyperlink tool over the line until a file name appears. Then click to see the image.)

10. Where is the oceanic lithosphere thicker—near the center of the ridge, or far away from it?

- Return to ArcMap and close the block diagram window.
- Turn off the **Block Diagrams** layer.

The spreading ridges are locations where new ocean crust is created. The young, hot, new crust is less dense and rises higher than the surrounding older, colder, denser rock due to *isostasy*—the same process that allows the continents to rise higher than the ocean floor.

In addition to the continental shelves and mid-ocean ridges, there is another type of feature that reveals how the oceans are created and destroyed. You will explore examples of this type of feature next.

### Trench flythrough animation

To view a simulated “flight” through a trench, click the Media Viewer button and choose **Trench Flythrough** from the media list.



### Where does old ocean crust go?


If the deepest parts of the ocean basins are not in the middle of the basins, then where are they?

- Turn on all the **Bathymetry** layers.
- Using the color scale of the bathymetry layers, locate three regions anywhere on the ocean floor with depths greater than –6 km. They should appear dark blue or purple on the map. (Hint: there are many in the Pacific Ocean.)


These regions are *trenches*, the deepest parts of the oceans. At trenches, oceanic lithosphere is subducted and plunges down into the mantle to be recycled (see the **Trench Flythrough** animation in sidebar).

11. On Map 1 (page 35), mark and label (T) the locations of three trenches.

 Turn off the **Countries** layer.

 Turn off the **Ridges** layer.


### Down the trenches

 Turn on and select the **Ocean Profiles** layer.

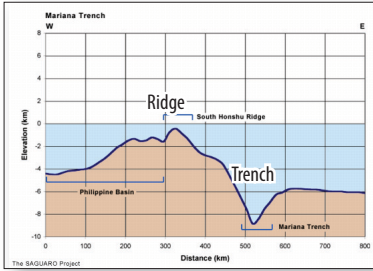
This layer displays bathymetric profiles of selected regions of the ocean floor. You may also view an animation to better understand the profiles and how they are related to block diagrams.

 Click the Media Viewer button .

 Choose **Topographic Profiles** from the media list.

 View the movie and close the Media Viewer window.

 Use the Hypelink tool  to click on profiles that cross areas that you think contain trenches.



**Figure 4.** Identifying ridges and trenches in a bathymetric profile.

### The deepest points on Earth

The profiles drawn in the **Topographic Profiles** layer do not necessarily cross the deepest part of the trench along its length. The maximum depths (km) recorded for each trench are listed below.

Trench Name	Maximum Depth <i>km</i>
Aleutian	8.1
Atacama	8.1
Java	7.7
Kuril	10.5
Mariana	11.0
Middle America	6.6
Puerto Rico	8.6
South Sandwich	8.3

12. Record the name of a trench in the Atlantic Ocean basin. Use the profile graph to estimate the maximum depth along the profile and record it below (see Figure 4 at left for help interpreting bathymetric profiles).

a. Name —

b. Maximum Depth —

13. Record the name of any trench in the Pacific Ocean basin. Use the profile graph to estimate the maximum depth along the profile and record it below. Remember that because of the map projection, the Pacific Ocean basin appears on ~~the right-~~ and left-hand sides of the screen.

a. Name —

b. Maximum Depth —

 Turn off the **Ocean Profiles** layer.

The process of creating and destroying the ocean floor results in the opening and closing of ocean basins. The formation of ocean floor at ridges often begins by breaking apart a continent. As the ridge develops, so does the ocean floor. Over time, a major ocean basin may form.

You may also view an animation showing how the processes of ridge spreading and subduction work.


 Click the Media Viewer button .


 Choose the **Ridge Spreading and Subduction** movie from the media list.

 View the movie several times and close the Media Viewer window.

## What will happen next?

Changes in the shapes of ocean basins occur continuously as new ocean floor is created at ridges and destroyed at trenches. The tectonic plates can reveal where more crust is being created than destroyed.

 Turn on the **Ridges** layer.

 Turn on the **Trenches** layer.



These layers show the locations of spreading ridges and trenches. Each ridge and trench represents a plate boundary.

 Turn off and collapse all bathymetry layers.

 Turn on the **Countries** layer.



 Turn on the **Relative-Plate Motion** layer.

This layer shows pairs of arrows on opposite sides of plate boundaries. The size of the arrow represents the speed at which the plates are moving relative to each other at that location. Each arrow points in the direction that its plate is moving relative to the neighboring plate.

 Use the Zoom in tool  to examine the Atlantic Ocean basin, including any ridges, trenches, and relative plate-motion arrows.

14. Would you expect the Atlantic Ocean basin to grow larger or become smaller over time? Explain.

 Click the Full Extent button  to view the entire map.

 Next, use the Zoom in tool  to examine the Pacific Ocean basin, including any ridges, trenches, and relative plate-motion arrows.

15. Based on the surface features and relative-plate motions, would you expect the Pacific Ocean basin to grow larger or become smaller over time? Explain.

In this investigation, you have seen that discoveries in the past hundred years have led to a revolution in our understanding of the ocean floor and the processes that shape it. This knowledge has provided important clues to help us interpret Earth's present condition, reconstruct its past, and predict its future.

 Quit ArcMap and do not save changes.