# THE OCEANS OF OUR PLANET

You might be surprised to see that the first module of this course will focus on the physical structure and makeup of the oceans. The geological processes in our world shape and influence marine systems, affecting water depth, determining the material on the seafloor, and controlling the nature of marine environments. Therefore, it is important to understand these environments before we begin to study the organisms that live there. In this module, you will learn about the geography of the ocean basins, the properties of seawater, and how ocean water circulates.

## *dive in*

The biology of the oceans cannot be fully "fathomed" unless you have a good understanding of the environment in which organisms live. Think about the types of environments that exist on land: deserts, rain forests, mountains, tropics, wide-open plains, small islands, and more. All of these create unique living situations for organisms. With almost three-fourths of the world covered by ocean environments, exploring their wide array of physical properties will give you a greater appreciation of the perfectly designed organisms that live in all of these habitats!

### THE GEOGRAPHY OF THE OCEANS

Did you know more of the world is covered with oceans than land? In fact, about 71% of the world is covered by water. This water is not distributed equally over the globe, however. There is more ocean area in the Southern Hemisphere than in the Northern Hemisphere. Almost two-thirds of our planet's land area is located in the Northern Hemisphere, while 80% of the Southern Hemisphere is covered by water! There are 4 large ocean basins on the earth. Each is a very large saucer-like depression of the seabed and contains a named ocean. A fifth ocean encircles the continent of Antarctica as shown in Figure 1.1.

**FIGURE 1.1**
**The Earth and Its Ocean Basins**
Illustration by Colin Gunn


The largest and deepest of these oceans is the **Pacific Ocean basin**. It is almost as large as the other 3 basins put together. The **Atlantic Ocean basin** is the next largest. The **Indian Ocean basin** is a little smaller than the Atlantic, but it is similar in depth. The Southern Ocean is not a true basin, but is a large, circumpolar body of water connecting all the oceans above it. Finally, the **Arctic Ocean basin** is the smallest and shallowest (see Table 1.1). These 5 oceans are connected to various shallower seas, many of which are probably familiar to you. The Caribbean, Arabian, and Mediterranean Seas, as well as the Gulf of Mexico, are a few examples of these shallower seas.

**TABLE 1.1**
**Average Depths and Sizes of the 4 Major Ocean Basins of the Earth and the Southern Ocean**

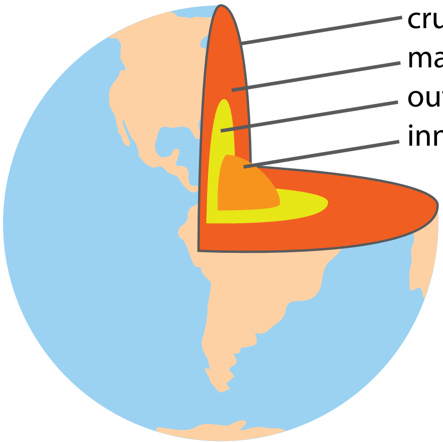
| Ocean | Average Depth (meters) | Approximate Area (sq. km) |
|---|---|---|
| Pacific | 4,190 | 166,000,000 |
| Atlantic | 3,740 | 86,500,000 |
| Indian | 3,870 | 73,000,000 |
| Southern | 4,500 | 20,327,000 |
| Arctic | 1,330 | 9,500,000 |

If you look at Figure 1.1, you can see how the Pacific, Atlantic, Southern, and Indian oceans are connected to each other. There also are waterways that connect these oceans to the Arctic Ocean in the north, making the oceans of the earth one vast system. This makes it possible for seawater and some organisms to move from one ocean to another.

## THE EARTH'S STRUCTURE

Now that we have discussed the placement of the land and ocean surfaces on the earth, let's take a look at what is below them. The earth is made up of various layers, as shown in Figure 1.2.

**FIGURE 1.2**
**Section through the Earth Showing Its Layers**
Illustration by Colin Gunn




Although no one has ever traveled through the earth's crust, much less to its center, scientific tests have helped to reveal the makeup of these layers. At the center of the earth is a core that scientists believe is primarily made up of iron. This layer experiences extreme pressure: over a million times the pressure at the surface of the earth. The temperature in the core is estimated to be over 4,000 °C. In fact, the inner core pressure is so great that the iron remains a solid. The outer core experiences slightly less pressure than the inner core, so the iron there is in a liquid state. It is believed that the movement within this liquid outer core produces the earth's magnetic field. The next layer is the mantle, made up of rock that is near its melting point. It is primarily in a solid phase, but it melts with slight temperature or pressure changes. Therefore, the mantle is in a constantly fluctuating state between liquid-like material and solid-like material that can swirl and mix around. This slow-flowing material, called **plastic rock**, sometimes behaves like a liquid and sometimes like a solid.

The outermost layer of the earth is the crust and is much thinner than the other layers. The crust "floats" on top of the plastic rock of the mantle. There is a vast difference between the composition and thickness of the crust under the ocean and the continents. You probably have studied a lot of this in earlier science classes, so I won't be covering this topic much more except to distinguish between 2 types of crust. Geologists explain that the difference between ocean and continents is caused by the chemical and physical differences in the rocks, not whether they are covered by water. The part of the earth that is covered with ocean is made up of **oceanic crust**, composed mainly of **basalt** (buh salt'). Basalt is solidified lava that is usually dark in color. The second type of crust is **continental crust**, and it is primarily composed of **granite**, a substance that is chemically different from basalt and has a lighter color. Oceanic crust is denser than continental crust and therefore "floats" a little lower on the mantle than continental crust. It is also much thinner than continental crust. Oceanic crust is about 5 km (3 miles) thick, while continental crust is on average 20–50 km (12–30 miles) thick.

**Oceanic crust**—The portion of the earth's crust that primarily contains basalt, is relatively dense, and is about 5 km thick

**Continental crust**—The portion of the earth's crust that primarily contains granite, is less dense than oceanic crust, and is 20–50 km thick

Complete "On Your Own" questions 1.1–1.2 before moving ahead.

## ON YOUR OWN

1.1 What are the 4 major ocean basins of the world? What is the fifth ocean?

1.2 You have a sample of oceanic crust and a sample of continental crust. How can you tell which is which?

## CONTINENTAL DRIFT AND PLATE TECTONICS

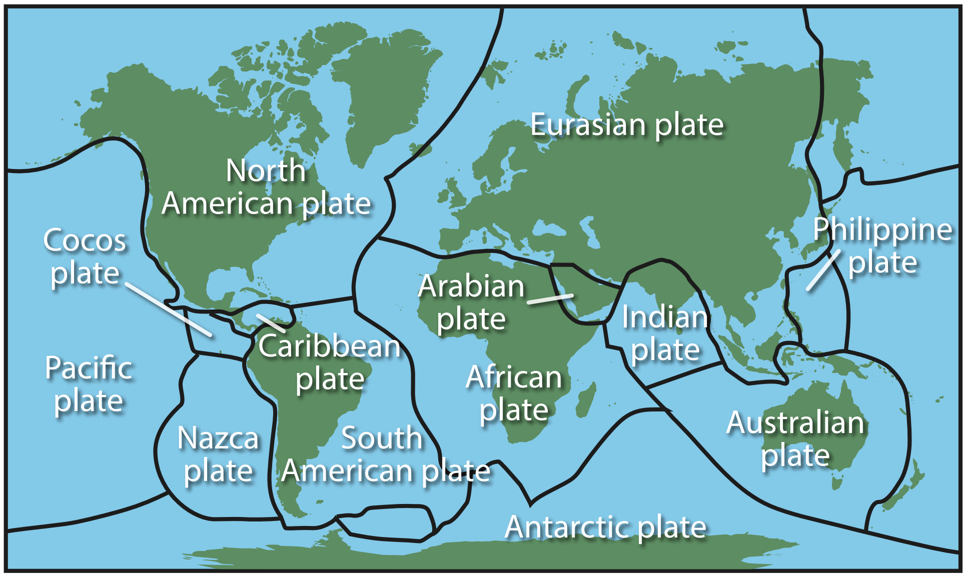
As early as the 1600s, scientists began looking at the shape of the continents and noticed they seem to match up like puzzle pieces. This led many to suggest that the continents may have been joined at one time in our earth's history. Later, other similarities between continents were discovered. Coal deposits and fossils on opposite coasts of the Atlantic Ocean are so similar that they seem to be parts of a greater whole. In 1912, a German geophysicist named Alfred Wegner came up with a detailed hypothesis of **continental drift** as an explanation for this data. He suggested that all the continents were once part of a large supercontinent called **Pangaea** (pan jee' uh). He believed that this large land mass began breaking up and the continents slowly moved away from each other to their present positions today. This idea was not well received in the scientific community of that time because Wegner did not have a believable explanation for the force required to move the land masses. Later, as more evidence supporting this theory was discovered, scientists began to agree that the continents do indeed drift. They named the process that moves them **plate tectonics**.

**Plate tectonics**—A process involving the movement of large plates on the earth's mantle

Plate tectonics is based on the idea that the earth's crust is divided into giant, irregular plates that float on the dense mantle of the earth. Scientists now believe that the radioactive decay of elements in the earth's mantle and the resulting heat cause plate movement. They think that as the heat rises through the plastic rock of the mantle, it generates currents that move the plates floating on the plastic rock. To visualize this, imagine a large Styrofoam rectangle floating in a swimming pool. The Styrofoam would represent Pangaea, and the water would represent the plastic rock of the earth's mantle. Now imagine that you add pressure to the foam until cracks form, yet you hold the many pieces together in their original shape. Once you let go, the pieces, representing plates, will float away from each other due to the movement of the water molecules beneath them. If you heated the water below the Styrofoam, water molecules would move faster, making the pieces float away from each other more quickly. Heat-induced motion of the various compounds in the plastic rock of the mantle could cause the continents to float away from each other in a similar way.

According to the theory of plate tectonics, the continents are resting on various plates of the earth's crust, as shown in Figure 1.3.

**FIGURE 1.3**
**Major Plates of the Earth's Crust**
Illustration by Colin Gunn




At the locations where the plates meet (the dark lines in the figure), there are 2 types of geological structures: a **mid-ocean ridge** system or a **trench** system. The mid-ocean ridge system is made up of a continuous chain of volcanic underwater mountains. These ridges extend all around the earth and are the largest geological features on the planet!

**Mid-ocean ridge**—A continuous chain of underwater volcanic mountains encompassing the earth

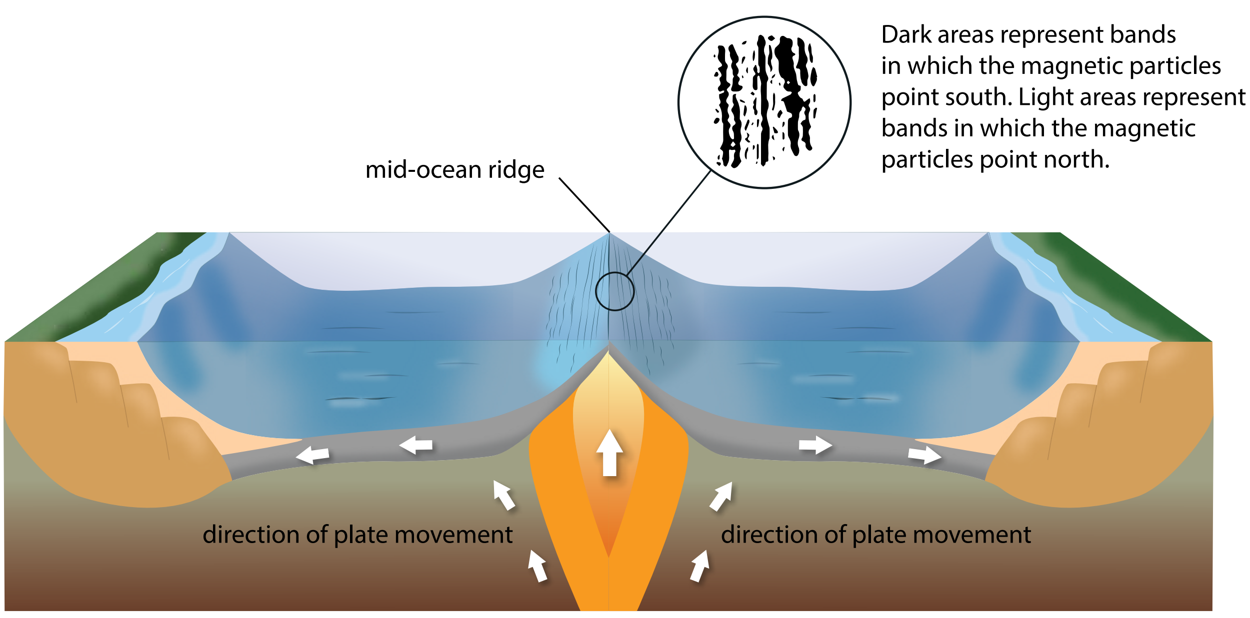
Some mountains of the various mid-ocean ridges rise so high that they actually extend above the ocean's surface and form islands, such as the Azores in the Atlantic Ocean. These ridges snake along the ocean floor, following the edges of the continents. At other sites where plates meet, there is a system of deep depressions, or trenches. These trenches, especially common in the Pacific Ocean basin, also seem to follow the shape of the nearby land masses. You will learn how the ridges and trenches form later on.

Now let's talk about some facts and data that scientists began to gather in relation to these ridges and trenches. First, scientists discovered that there is a large amount of geologic activity around both ridges and trenches. Although both locations experience earthquakes and have volcanic activity, earthquakes are more common around ridges, and active volcanoes are more likely to be found near trenches.

Second, a very interesting phenomenon was discovered around the mid-ocean ridges. Geologists already knew that there were times in our earth's history when the magnetism of the earth had reversed. This means that during these reversal periods, a magnetic compass would point to the earth's South Pole instead of the North Pole (which, of course, is where it points today)! How do scientists know this? Well, in molten rock, there are tiny magnetic particles that move to align themselves toward the earth's magnetic north. As the rocks cool and harden, those magnetic particles are frozen so that they always point to what was magnetic north when the rock cooled. Geologists have discovered many layers of igneous rock (rock that forms when molten rock cools) in which the magnetic particles point south, not north. This means those rock layers must have cooled when the earth's magnetic field was the opposite of what it is today.

As scientists sampled the rocks on the seafloor near the mid-ocean ridges, they began to see a pattern of bands running parallel to the mid-ocean ridge, representing groups of rock that have alternating magnetic orientations! In other words, the magnetic particles of some bands point north while those of other bands point south. In fact, the bands are symmetric around the mid-ocean ridge so that the pattern on one side of the ridge is a mirror image of the pattern on the other side of the ridge (see Figure 1.4). These magnetic particles that are pointing in the "wrong" direction are called **magnetic anomalies** (uh nom' uh leez), and they suggest that the bands of igneous rock on the ocean floor were formed from molten rock at different times in the earth's history.

**FIGURE 1.4**
**Alternating Magnetic Orientations of Rocks at the Mid-Ocean Ridge of the Atlantic Ocean**
Illustration by Colin Gunn



Think about what this means. The seafloor in these areas was likely not formed all at one time, at least where the bands of reversed magnetization are. If the bands of igneous rock near the mid-ocean ridge were formed during different times in the earth's history, the sections of the earth's crust near the mid-ocean ridge seem to be *moving away from each other*. A crack in the crust results from this separation; we call it a **rift** between the plates.

As the plates move away from each other, there is less pressure on the mantle below the rift. That's because the crust is not weighing it down as much. The release of pressure allows the mantle material to melt enough to become liquid and rise up through the rift. This melted rock, now called **magma**, pushes up against the rift area, creating a raised ridge. Once it reaches the surface, the magma cools and becomes new oceanic crust. Scientists call this process **seafloor spreading**, and it explains many of the discoveries found around the ocean ridges.

**Seafloor spreading**—The process that creates new seafloor as plates move away from each other at the mid-ocean ridges

You probably would expect, then, that the crust at the ridges is newer than the crust farther away from the ridges. As a result, the crust near the ridges has had less time to accumulate sedimentary material. That explains why the sediments of the ocean floor are thicker farther away from the ocean ridges. It also explains why we find that pattern of magnetic rocks mirrored on both sides of the ridge. As the magma seeped up through the ridge, it cooled, trapping the magnetic material in the rocks, which were pointing in the direction of magnetic north. Then when the earth's poles were reversed, the magnetic material in the cooling magma was fixed pointing in the opposite direction.

## think about this

Although tectonic plates are moving slowly today, in 2005 a 60-km crack opened up on the continent of Africa in a period of just 10 days. The chasm formed in the country of Eritrea and was 8 meters in width and has continued to expand in recent years. Scientists believe this is going to eventually create a new ocean! Hot, molten rock coming from the earth's mantle is seeping to the surface to create the split. As these underground eruptions continue, the horn of Africa is predicted to fall away from the continent eventually, resulting in a new large island formed from parts of southern Eritrea and Somalia. Researchers are amazed at the speed of the plate transformation, but that should not be surprising if we understand that there have likely been times in the earth's past that plate movement and seafloor spreading were rapid.

Now let's put all of this information together to understand what scientists believe about the ocean floor. Seafloor spreading and plate tectonics are closely related to one another and indicate that the earth's crust is divided into giant irregular plates that float on the denser mantle material below. Each plate is bounded by oceanic trench or ridge systems. Some plates are made of both oceanic and continental crusts. New oceanic crust material is formed at the mid-ocean ridges, and as it moves away from the ridges, it carries the bottom sediments and continental land masses with it. Now this rate of movement is extremely slow; today the plates move at a rate of between 2 and 18 cm per year. That's about as fast as your fingernails grow!

I want to stop here and discuss this phenomenon for a moment. The Atlantic Ocean is up to 1,000 miles wide and is believed to be a completely new ocean that formed when

Pangaea broke apart. If it always grew at its present rate, it would have taken millions of years to get to the size it is today. However, there is no strong evidence to suggest that the rate of the ocean's growth has been constant. In fact, many parameters of our earth have not been constant over time, including its magnetic field. Thus, there is no reason to believe that the plates have always moved slowly. During a catastrophic event, the plates might have moved apart from each other quickly. There is a very detailed mathematical model of **catastrophic plate tectonics** that predicts rapid plate movements during the worldwide Flood that occurred in Noah's day.

There is also some evidence for such rapid plate movement. You see, many of the magnetic reversals of the earth may have occurred quickly, in a matter of days. Scientists have found evidence of a thin lava flow where the outside cooled first (displaying one particular magnetic orientation) and the inside cooled days later with evidence of a magnetic reversal! If magnetic reversals happened quickly, then the bands of magnetic particles near the mid-ocean ridge may have formed quickly as well, or the magnetic reversals would not have been captured in the rocks. This, then, is possible evidence that the seafloor might have spread very quickly in the past.

Complete "On Your Own" questions 1.3–1.4 before moving ahead.

### ON YOUR OWN

1.3 If a scientist discovered fossils of an extinct reptile on the west coast of southern Africa, and he knew that more examples of the same extinct fossil were found on the east coast of South America, would this discovery prove that the supercontinent Pangaea was a reality?

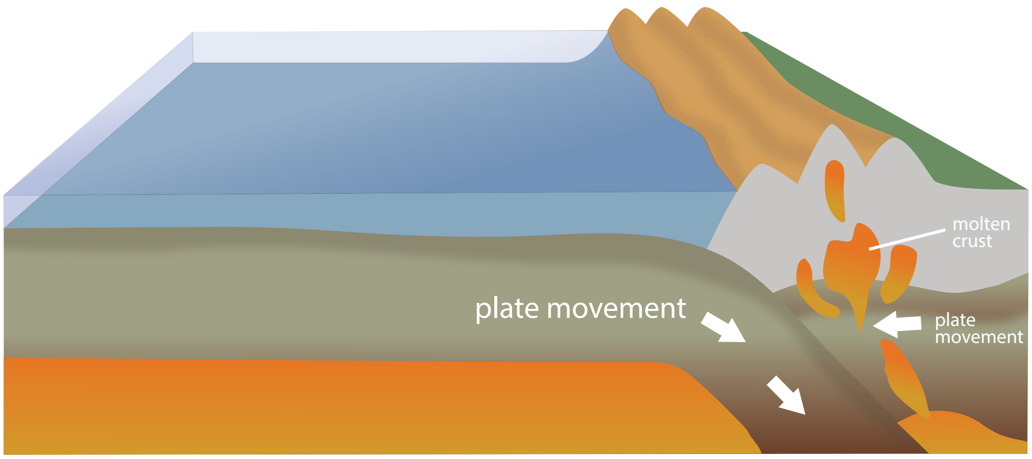
1.4 If you were on a scientific expedition in the deep Atlantic Ocean, took a sample of the seafloor, and found that it had a very thick layer of sediment, would you presume that this area was close to or far from a mid-ocean ridge? Why?

## PLATE INTERACTIONS

At this point in our discussion, let me pose a question: If new oceanic crust is forming at the rift, why isn't the surface of the earth increasing in size? Well, thankfully, the earth does not increase in size because when new ocean floor is formed, plates are destroyed in another part of the world. This is where the trenches I talked about earlier come into play. A trench is formed when 2 plates are moving toward each other, and one of the plates dips below the other, sliding back down into the mantle. Figure 1.5 shows this process, called **subduction**.

**Subduction**—The downward movement of 1 plate into the earth's mantle when 2 plates collide

**FIGURE 1.5**
**Subduction Resulting from 2 Plates Colliding**
Illustration by Colin Gunn




Once the plate enters the mantle, the extreme heat and pressure begin to break it up. This violent churning can sometimes result in an earthquake. The plate material eventually melts, and some rises back up to form volcanoes.

The interaction of plates at a trench depends on the types of plates that are colliding. For example, if an oceanic plate collides with a continental plate, the oceanic plate will sink into the mantle. Remember, it is made of denser oceanic crust and will naturally move below the less-dense continental crust. At these types of trenches, continental volcanoes form vast mountain ranges, such as the Andes Mountains in South America. In this particular instance, the oceanic Nazca Plate in the southeast Pacific collides with and sinks below the continental South American Plate.

Explore how this happens in Experiment 1.1.

# EXPERIMENT 1.1
## MOUNTAIN FORMATION FROM PLATE MOVEMENT

**PURPOSE:** To explore the interaction of an oceanic plate with a continental plate

**MATERIALS:**
- A rectangular clear plastic or glass container, approximately 4 inches wide by 5 inches long (a disposable 24-ounce plastic container was used in the photos)
- Measuring cup
- 1 cup of salt
- 1 cup of unbleached sugar (Cinnamon sugar or a type of colored salt can also be used, as long as it is noticeably different in color than salt.)
- A spatula that is slightly smaller in width than the container width (You can substitute a sturdy piece of cardboard cut to the appropriate size.)

**QUESTION:** What happens when a denser plate sinks below one that is less dense?

**HYPOTHESIS:** Write down your hypothesis about what happens to the less-dense plate.

**PROCEDURE:**

1. Measure ½ cup salt and pour into the container. Gently shake the container side to side to allow the salt to settle so the surface becomes flat.
2. Measure ½ cup dark sugar and pour over the salt, trying to disperse it evenly. You are attempting to create even layers. Gently shake the container side to side to help it settle more evenly.
3. Measure ½ cup salt and pour over the sugar, again trying to disperse it evenly. Again gently shake the container side to side to help it settle.
4. Measure ½ cup dark sugar and pour over the salt, evenly dispersing it. Shake the container side to side to help it settle.
5. You should now have 4 somewhat even layers of material in your container that look similar to the image below.

6. Carefully insert the spatula in one side of the container so that the blade is perpendicular to the table.
7. Gently drag the spatula toward the center of the container so that the layers of material begin to bunch up on one side. You should see something like this:

8. Note the shape of the layers formed. Make a sketch in your lab notebook of the result.
9. Clean up and return everything to the proper place.

**CONCLUSION:** What did you observe? What happened to the layers as the spatula pushed toward them?

In the experiment, as the spatula moved from one side of the container toward the middle, the layers began to build up on each other. This is what happens when a denser oceanic plate pushes toward a less-dense continental plate. As the oceanic plate moves down into the mantle, it pushes toward the layers of the continental plate, causing them to build up. That forms mountains, and because they are located where 2 plates collide with each other, these areas will be prone to earthquakes or even volcanic activity.

In some places, 2 *oceanic* plates will collide, and one will dip below the other to form a trench. This too will result in volcanoes and sometimes form volcanic islands. A good example of this phenomenon is where the oceanic portion of the North American Plate collides with the oceanic Pacific Plate, creating the Aleutian Islands in the northern Pacific Ocean.

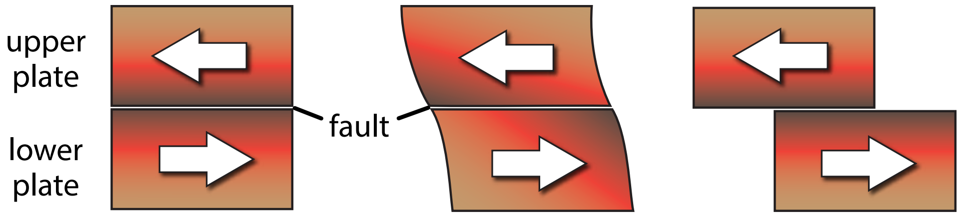
Lastly, 2 *continental* plates can collide. Since they are essentially the same, relatively lesser density, neither will move under the other. Instead, in place of a trench, the 2 land masses will push against each other with great enough force to cause the rocks to bend and buckle, building up on top of each other. This folding of rock can form large mountain ranges, such as the Himalayas. The Himalayas were believed to be formed when the plate of India collided with Asia.

In addition to mid-ocean ridges, trenches, and mountain ranges, another type of plate boundary can occur when 2 plates slide past each other. In this boundary, no new plate material is formed and none is destroyed. This type of boundary is called a **shear boundary** and results in a fault.

## think about this

Ocean trenches are the deepest places known in the oceans. Yet with the extreme heat and pressure at these locations, you may be surprised to learn that scientists are discovering living things here. And not only are they being found at the trench depths, but they are also being found much, much deeper. Marine biologists have discovered that microorganisms can live deep beneath the seafloor, among the tiny crevices in the rocks of the crust. Communities of these microbes have been found up to 3 km below the seafloor and are believed to be living up to 10 km deep. That is over 6 miles down in the ocean crust! They grow through a process known as chemosynthesis, using the chemical energy bound up in the rocks. Additionally, this bountiful food source led scientists to believe there could be other organisms living in the crust. Recently, worms have been discovered living over 3 km below the ocean floor, apparently feeding on the microorganisms living there. Indeed, there are fewer places on our planet too harsh for life than many people assume!

**FIGURE 1.6**
**Diagram of a Shear Boundary**
Illustration by Colin Gunn




As 2 plates slide past one another, a large amount of friction restricts their movement until a sudden release of pressure results in an earthquake.

The parallel movement of the plates along the fault is not smooth because there is a great deal of friction between them. Figure 1.6 shows that as the plates become stuck against one another, pressure builds up as they try to move. When they finally do move, they slide all at once, resulting in an earthquake. The San Andreas Fault in California is an example of a shear boundary and, as you probably know, is responsible for the many earthquakes that occur there. As you can see, this model of seafloor spreading and plate tectonics explains many observations made by geologists.

## FEATURES OF THE OCEAN BOTTOM

Because the process of plate tectonics is a global one and the ocean floor structure is a result of that phenomenon, you should expect that the ocean floor is similar all around the world. We can divide the ocean floor into 2 major areas: the shallow margins around the continents and the deep-sea floor.

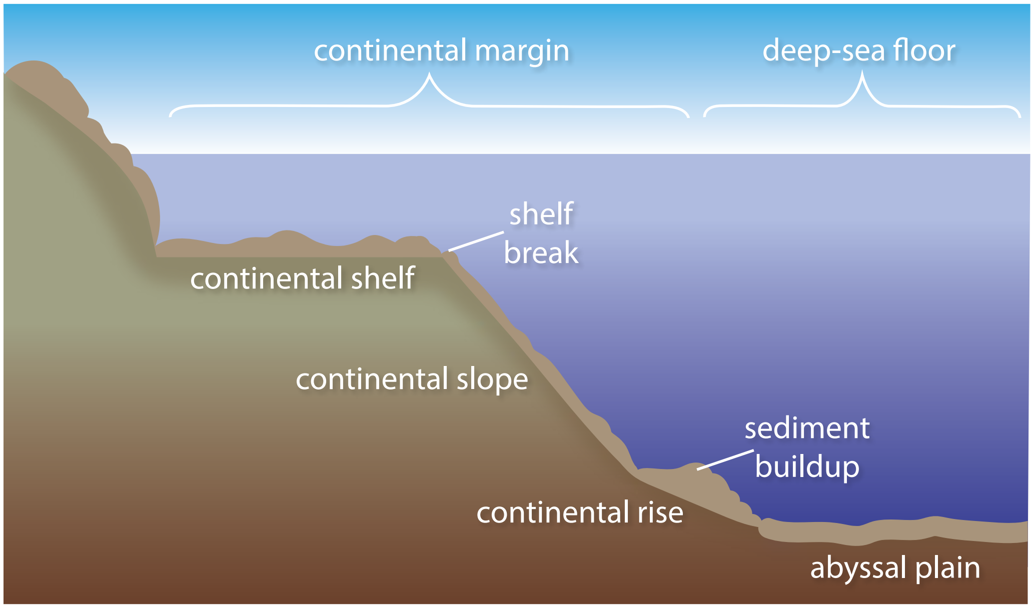
The continental margins can be divided into 3 main regions, as shown in Figure 1.7. The continental shelf begins at the shoreline of the continents and extends seaward. It is a structural part of the continental landmass and would not be under the ocean if sea levels were to drop by as little as 5%.

**Continental shelf**—The gently sloped, shallow section of the edge of a continent, extending from the shore to the point where the slope gets steeper

Continental shelves make up only about 8% of the ocean's surface area, but they contain the richest diversity of marine life. This is due to the fact that more light reaches the seafloor at the continental shelf, resulting in more producers, such as plants and algae. More producers mean a greater opportunity for animal life, as animals are consumers and therefore need to eat producers. The shelves are relatively smooth, sloping gently outward toward the sea. The outer edge of the shelf, where the bottom begins to become steeper, is called the shelf break. This occurs at depths of 120–200 meters and marks the beginning of the second region, the continental slope.

**Continental slope**—The steeper section of a continental edge, extending seaward from the continental shelf

**FIGURE 1.7**
**Diagram of the Ocean Bottom**
Illustration by Colin Gunn



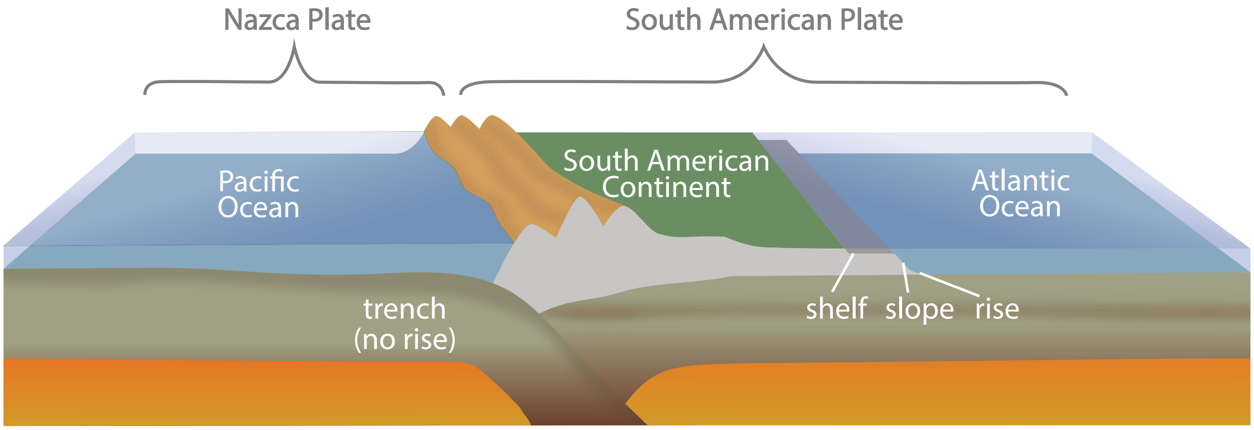

Deep at the base of the continental slope is a buildup of sediments resulting in the third region, the continental rise, which continues down to the seafloor.

**Continental rise**—The gently sloping area at the base of the continental slope

Because of its location at the foot of the more steeply graded continental slope, the continental rise collects debris and sediment. In fact, this is likely how the rise was formed. As sediments from the continental shelf worked their way down toward the deep sea, they began to accumulate at the foot of the continental slope, creating a raised area full of sediments.

Now, I want you to understand that there is not a defined continental rise everywhere the continent meets the deep-sea floor. This is due to plate-to-plate interactions. A good example of this is the continent of South America. The South American continent rests on the South American Plate (see Figure 1.8). It is moving away from the mid-Atlantic ridge, heading in a western direction. It bumps up against the Nazca Plate, forming a deep trench on the western perimeter of the South American Plate. Remember, I already mentioned as the Nazca Plate moves below the South American continental plate, it forms a trench and mountains. So the sediments at the base of the continental slope there are either carried down into the trench or pushed up onto the continent as the Andes Mountains are forming. Therefore, the eastern coast of South America has no real plate activity and contains a buildup of sediment, resulting in a continental rise. But the western coast has active motion and lacks a noticeable continental rise.

**FIGURE 1.8**
**The Continental Margins of South America**
Illustration by Colin Gunn




## ON YOUR OWN

**1.5 If an oceanic plate is colliding with a continental plate, what will most likely happen?**

**1.6 You are given a sample of sediment from the ocean. The container says it is a small sample taken from a large amount of sediment buildup. From which region of the ocean floor did the sample most likely come: the continental shelf, continental slope, continental rise, or abyssal plain?**

The fourth region of the seafloor lies at a depth of 3,000–5,000 meters (10,000–16,500 ft) and is almost flat. This flat seafloor area is called the **abyssal** (uh bis' uhl) **plain**, and it gently slopes upward toward the mid-ocean ridges. Though this region is relatively flat, there are areas in the ocean where you will find hills, plateaus, and other geologic structures. Additionally, you may think the abyssal plain is the deepest part of the ocean, but remember the trench systems we discussed? In the trench areas, the ocean is at its deepest, reaching depths of 11,020 meters (6.8 miles) in the Mariana Trench of the Pacific, the deepest-known place in all the oceans.

Complete "On Your Own" questions 1.5–1.6 before moving ahead.

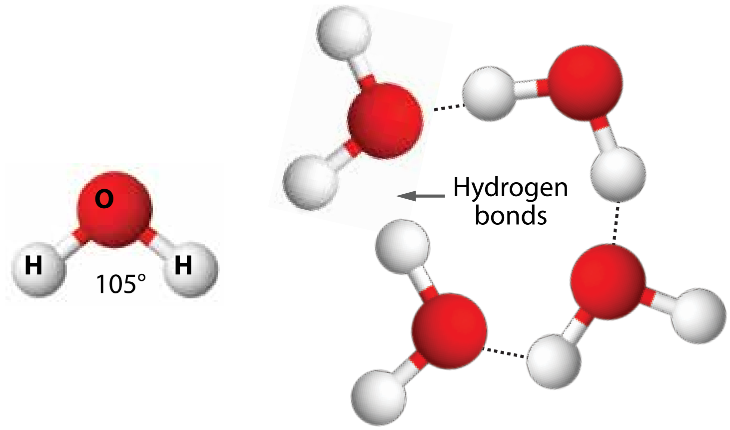
## PROPERTIES OF WATER

I have gone into great detail about the "containers" of ocean water. Now it is time to discuss the nature of what those containers hold. To understand the sea life in ocean water, you must understand the behavior and makeup of water. Water comprises 80–90% of the volume of most marine organisms and provides body support for many of them. It also is the medium for most chemical reactions needed to sustain life.

You probably already know that the chemical composition of water is $H_2O$, but you may not fully understand what that means. Well, all matter is made up of tiny particles called atoms. When 2 or more atoms are chemically combined into a larger particle, the result is a molecule. A water molecule is made up of 1 relatively large oxygen atom and

2 smaller hydrogen atoms; thus, 2 Hs and an O. The 3 atoms of a water molecule form an angle, with the oxygen atom at its vertex, as shown in the left portion of Figure 1.9.

**FIGURE 1.9**
**The Water Molecule and Hydrogen Bonding**
Illustration by Colin Gunn




Each slightly negatively charged center of a water molecule attracts the slightly positively charged ends of other water molecules, creating hydrogen bonds.

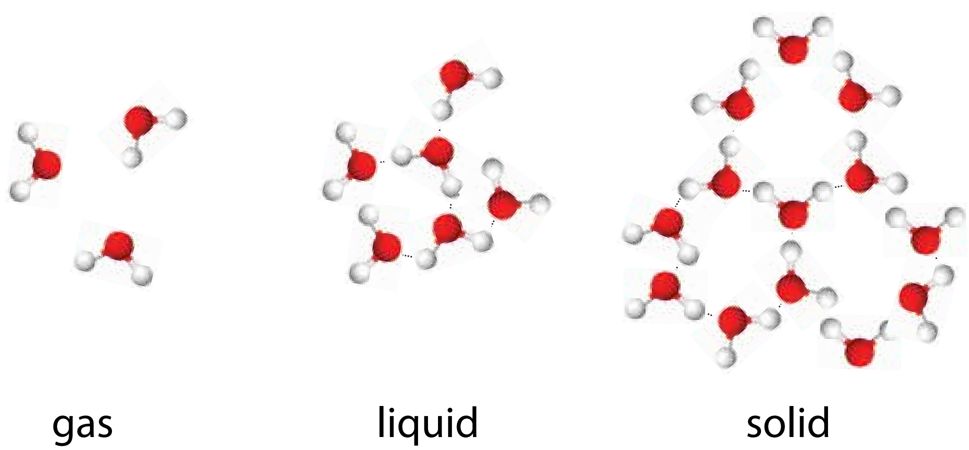
The bonds between the hydrogen atoms and the oxygen atom of a water molecule are formed by sharing 2 negatively charged electrons. The oxygen atom has a stronger pull on these electrons, causing the oxygen at the center of the molecule to have a slight negative charge. This leaves the hydrogen ends of the molecule with a slight positive charge. Each area of a water molecule, then, attracts the oppositely charged areas of other water molecules. The resulting attraction between water molecules forms a weak bond, called a **hydrogen bond**, shown on the right side of Figure 1.9. These bonds are not as strong as the bonds within a molecule, but they make water different from most substances on the earth.

Hydrogen bonding creates a flexible skin at the surface of water. This is called surface tension, and it helps hold water molecules close to one another at the surface of a body of water. It is so strong that items such as needles and razor blades can float on the surface of water if they are placed there carefully. Even insects like the water strider can walk on water because of its surface tension. Without hydrogen bonding between molecules, water would be in a gaseous state at normal temperature and pressure, boiling at −80 °C and freezing at −100 °C. This would make the existence of life on earth impossible!

I want to discuss another amazing property of water. It naturally exists on earth in all 3 of the possible phases of matter: solid (ice or snow), liquid (what we normally call water), and gas (water vapor). This is unique. No other substance on earth naturally exists in all 3 states. The molecules in liquid water are moving constantly, and some are being held in small groups due to hydrogen bonding. These groups continually form and break apart. The molecules will move faster if the temperature of the water is higher. If a water molecule moves quickly enough, it may break free of all the hydrogen bonds and go from liquid phase to gaseous phase. This process is called evaporation, and you experience it whenever you take a hot shower and see the resulting fogginess in the air from the water vapor. As the temperature rises, so does the rate of evaporation, resulting in more and more molecules escaping the hydrogen bonds. In water vapor, the molecules are not held together by hydrogen bonds and are much farther apart than in the liquid phase.

As liquid water cools, the molecules move more slowly and pack closer together, taking up less space. This decrease in volume results in the cold water becoming denser. As a result, cold seawater will sink below warmer seawater. Freshwater also gets denser as it gets colder, but only down to a temperature of about 4 °C (39 °F). Below 4 °C, freshwater actually gets less dense as it cools (which is why solid ice cubes float in liquid water). Why does this happen? It is because of the hydrogen bonding. In the liquid phase, water molecules are free to get very close to one another to take full advantage of the hydrogen bonds. As the water begins to freeze, the molecules move apart from one another to fit into a crystalline arrangement in the solid phase. Since the molecules are farther apart from one another in the solid phase, solid water is less dense than liquid water.

**FIGURE 1.10**
**Structure of Water Molecules in Solid, Liquid, and Gas Phases**
Illustration by Colin Gunn




The solid molecules in Figure 1.10 take up more volume and therefore are less dense than water molecules in the liquid phase. This is actually an unusual situation. You see, most readily available chemicals are less dense in their liquid phase than in their solid phase. This unique attribute of water has important implications for aquatic organisms. Because ice floats, a sheet of ice acts as an insulating blanket that helps keep the liquid water below from cooling down too quickly. As a result, lakes and parts of the ocean are kept from freezing into a solid mass, allowing life to exist below the surface of the ice.

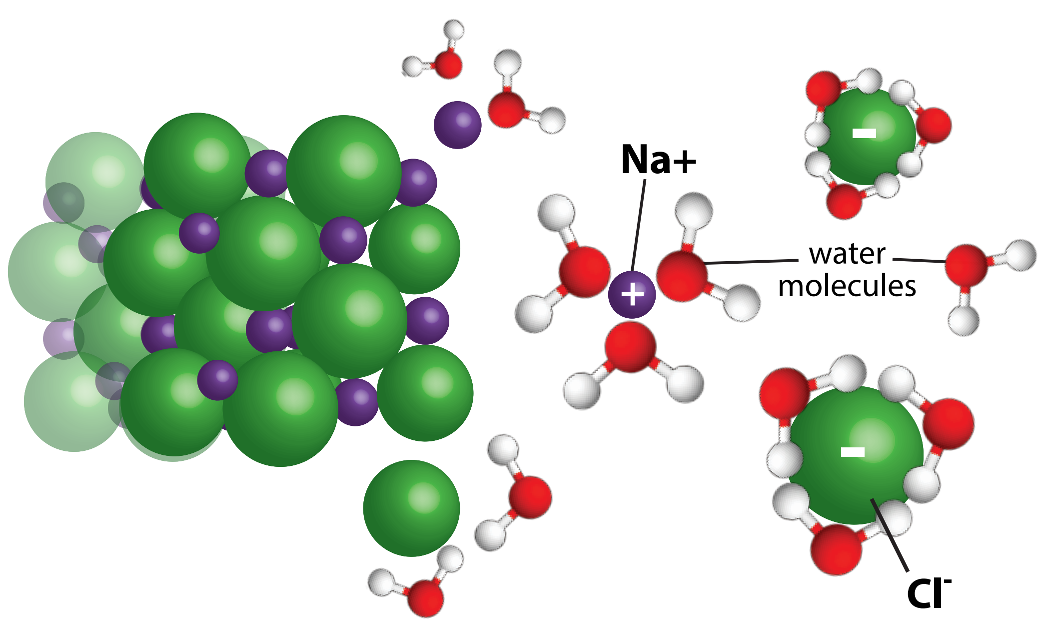
Water has another amazing property that results from its hydrogen bonds: It has a large specific heat.

**Specific heat**—The amount of energy required to raise the temperature of 1 g of a substance by 1 °C

It takes a lot more energy to increase the temperature of water by 1°C compared to most other substances. This is due to the hydrogen bonds keeping the water molecules together. The bonds have to be broken before the molecules can move around, which is what occurs when ice melts. Because of this, a large amount of heat must be added to water to warm it up. In the same way, a large amount of heat must be removed from a sample of water to cool it down. Fortunately for aquatic organisms, this means the temperature of water does not change very quickly, resulting in a more constant environment.

There is one more general property about water I would like to discuss: Water can dissolve more substances than any other natural material. A substance that can dissolve other substances is called a **solvent**, and water is known as the universal solvent. It is able to dissolve a lot of substances because of its small size and because of the slight electrical charges on the atoms of its molecules. Water is especially good at dissolving a class of molecules called **salts**, which are made of particles that have opposite electrical charges. These electrically charged particles are called **ions**, and they are either negatively or positively charged. Table salt (sodium chloride) is an example of an ionic molecule, consisting of a positively charged sodium ion ($Na^+$) and a negatively charged chloride ion ($Cl^-$). Remember, water molecules have a slight positive side (the hydrogen atoms) and a slight negative side (the oxygen atom). Ions have a stronger charge than the slight charges of water molecules, so when a salt crystal is placed in water, the strong electric charges on the ions attract the water molecules, causing a layer of water molecules to surround each ion (see Figure 1.11). This weakens the attractions that hold the salt crystal together, and it causes the salt crystal to break apart, or dissolve.

**FIGURE 1.11**
**The Dissolving of a Salt Crystal by Water**
Illustration by Colin Gunn



Complete "On Your Own" questions 1.7–1.8 before moving ahead.

## ON YOUR OWN

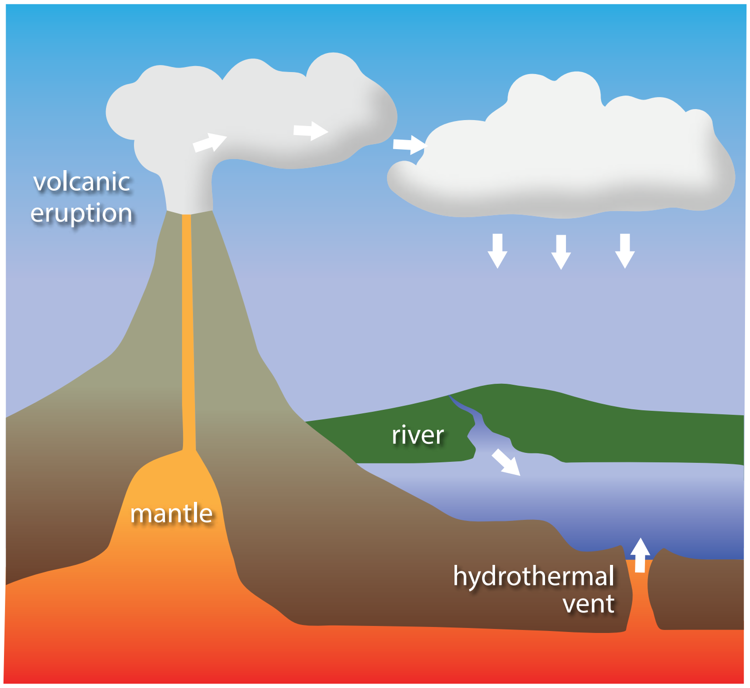
**1.7 What gives water many of its unusual properties?**

**1.8 Benzene is a chemical that is liquid at room temperature. If frozen benzene is placed in liquid benzene, will it float or sink?**

## SEAWATER

Now that we have covered a lot of background material, we can finally discuss seawater. Seawater consists of pure water with materials dissolved in it. The solids dissolved in seawater come from 2 main sources. Some solids come from the weathering of rocks on land and are carried to the ocean by rivers. Others come from the mantle areas of the earth and are released into the ocean through deep openings called hydrothermal vents. We will go into more detail about these areas of the ocean later in this course. Materials from the mantle can also reach the ocean by volcanic eruptions. This puts materials into the atmosphere that then enter the ocean by way of rain or snow. Study Figure 1.12 to see how dissolved solids get into seawater.

**FIGURE 1.12**
**How Dissolved Solids Get into Seawater**
Illustration by Colin Gunn




Positive ions, such as magnesium, potassium, and sodium, enter the ocean mainly by way of rivers. Negative ions, like chloride and sulfide, enter mainly through volcanic eruptions and hydrothermal vents.

If you have ever taken a swim in the ocean, your taste buds probably told you that salts make up the majority of dissolved substances in seawater. Sodium and chloride account for about 85% of the solids in the ocean. If we took a sample of seawater and allowed all of the water to evaporate, the material left behind would be the salts that had been dissolved in it. To see this phenomenon, perform Experiment 1.2. Note that this experiment requires a few days.

## EXPERIMENT 1.2
### REMOVING THE SALT FROM SALTWATER

**PURPOSE:** To explore the evaporation of saltwater

**MATERIALS:**

- A liquid measuring cup
- Water
- A small saucepan
- Stove
- A tablespoon
- Salt
- A metal stirring spoon
- A small bowl

**QUESTION:** How do scientists determine the salinity of ocean water? (This experiment will show you one way this can be done.)

**HYPOTHESIS:** Write down your hypothesis about what will happen to the salt in saltwater when the water evaporates.

**PROCEDURE:**

**NOTE:** If you live near the coast and have access to ocean water, you can place 2 tablespoons of ocean water in the bowl and skip to step 8.

1. Measure 1 cup of water into the measuring cup and pour it into the saucepan.
2. Place the saucepan on the stove and heat over medium heat. Do not let it boil.
3. Add 2 tablespoons of salt to the water while it is heating.
4. Stir the water until the salt dissolves and the water becomes clear again. It is okay if a bit of undissolved salt is left.
5. Turn off the stove and remove the saucepan.
6. Place 2 tablespoons of the saltwater mixture into a bowl, being careful not to

transfer any undissolved salts. The water should appear clear.

7. Clean up everything except the bowl that has 2 tablespoons of saltwater in it.
8. Allow the bowl of saltwater to sit out for a few days until all the water is gone. (This process will occur more quickly in a warm, sunny window.)
9. Observe what is in the bowl.
10. Clean up and return everything to the proper place.

**CONCLUSION:** Write something about what happened in the experiment.

In this experiment, you created saltwater, took a measured sample, and allowed all the water to evaporate out of it. What was left behind? You should have found crystals of salt in the bowl. You see, water can evaporate only in its pure form. It does not bring dissolved solids into the air with it. As a result, a scientist could take a measured sample of seawater and perform an experiment like the one you just did. He could then measure the amount of salt in grams, and that would determine the seawater's **salinity**.

**Salinity**—The total amount of salt dissolved in a solvent

Salinity is typically expressed as the number of grams of salt left behind when 1,000 grams of seawater are evaporated. The units we would use would be **parts per thousand**, or **‰**. For example, if we evaporated 1,000 grams of seawater and were left with 32 grams of salt, we would say that the salinity of the seawater was 32 parts per thousand, or 32‰. You may not be familiar with the "‰" symbol, but it is similar to the percent symbol (%). While "%" means a part of 100, the "‰" symbol refers to a part of 1,000, thus giving scientists the ability to measure amounts in smaller increments.

Instead of evaporation, modern scientists use electronic instruments to determine salinity. The electrical charges of ions enable them to conduct electricity quite well, so oceanographers can measure salinity by how conductive the water is.

The organisms that live in the ocean are strongly affected by salinity. Even the smallest change in salinity can affect or even kill some of them. However, with the exception of areas that experience regular changes, such as at the mouths of rivers, the salinity of the oceans stays relatively constant. As you study more about life on our planet, you will be amazed to see that in practically every habitat, no matter how harsh, some types of organisms are able to survive and even thrive there. This is the case at river mouths. These areas, where freshwater is constantly flowing into saltwater, contain many creatures that have specially designed mechanisms to cope with drastic salinity changes.

Organisms are affected not only by the total amount of salt in seawater but also the *kind* of salt. The more common ions found in seawater are shown in Table 1.2 and are grouped according to their abundance. The first 7 ions make up over 98% of the total salt concentration in seawater. Regardless of the salinity of an ocean area, the *relative* *concentrations* of these ions remain remarkably constant. In other words, no matter where you take a sample of seawater in the world, chloride ions will make up a similar percentage of whatever salt is present. This fascinating fact means that although marine organisms are exposed to possible salinity changes due to evaporation, rain, or other mechanisms, they don't have to deal with changes in the *ratios* of various ions. It is therefore easier for them to control their internal salt and water balance.

**TABLE 1.2**
**Ions Found in Seawater with 35‰ Salinity**

| | Ion | Concentration ‰ |
|---|---|---|
| Major Ions | Chloride | 18.9 |
| | Sodium | 10.5 |
| | Sulfate | 2.6 |
| | Magnesium | 1.3 |
| | Calcium | 0.4 |
| | Potassium | 0.4 |
| | Bicarbonate | 0.1 |
| Minor Ions* | Bromide | 0.065 |
| | Borate | 0.026 |
| | Strontium | 0.013 |
| | Fluoride | 0.001 |

*Other elements are found in trace amounts

## SALINITY, TEMPERATURE, AND DENSITY

We have already discussed how temperature affects the density of seawater. Cold liquid seawater is denser than warm liquid seawater and will sink below it to a lower depth. Well, it turns out that salinity influences the density of seawater too. Perform Experiment 1.3 to observe this.

# EXPERIMENT 1.3
## THE EFFECTS OF SALINITY AND TEMPERATURE ON THE DENSITY OF WATER

**PURPOSE:** To determine how salinity and temperature influence seawater density

**MATERIALS:**
- A measuring cup for liquids
- 6 clear drinking glasses
- Water
- A small saucepan
- Stove
- Measuring tablespoon
- Salt
- A stirring spoon
- 2 colors of food coloring (Yellow and blue work best.)
- Chilled water from the refrigerator
- A turkey baster

**QUESTION:** How do salinity and temperature influence the density of seawater?

**HYPOTHESIS:** Write down your hypothesis about what will happen to 2 layers of water when one is colder than the other. Also write what you think will happen to 2 layers of saltwater when one has greater salinity.

**PROCEDURE:**

**NOTE:** If you live near the coast and have access to ocean water, you can use 1 cup of ocean water instead of making saltwater in steps 1–3.

1. Measure 1 cup of tap water and place it in the saucepan on the stove.
2. Heat the water on medium heat and add 2 tablespoons of salt.
3. Stir until the salt is dissolved, then remove the saucepan from the heat to cool. Turn off the burner.
4. While the saltwater is cooling, perform the next part of the experiment by filling 2 of the glasses with tap water until they are one-third full.
5. Add 2 drops of blue food coloring to one glass and mix.
6. Add 2 drops of yellow food coloring to the other glass and mix.
7. Draw some of the blue water into the turkey baster, placing your finger over the tip so none will escape.

8. **Very carefully**, place the tip of the baster into the very bottom of the glass with the yellow water. **Slowly** squeeze the bulb of the baster so that the blue water is injected into the glass. You do not have to squeeze all the water out—just enough to observe where the blue water goes. Make a note of what happens. Rinse the baster with tap water.
9. For the second part of the experiment, fill a third glass with chilled water until it is one-third full.
10. Add 2 drops of blue food coloring and stir.
11. Fill the fourth glass one-third of the way with very hot water from the tap, being careful not to get burned. Add 2 drops of yellow food coloring to this glass and stir.
12. Using the turkey baster, draw some of the cold (blue) water and carefully place the tip of the baster into the very bottom of the glass with the hot yellow water.
13. **Very slowly**, squeeze the bulb of the baster so that the cold blue water comes out into the glass. Again, you do not have to squeeze all of it out—just enough to note where the blue water goes. Make a note of what happens. Rinse the baster with tap water.
14. Finally, once the saltwater has come to room temperature, fill the fifth glass one-third full of the saltwater and add 2 drops of blue food coloring to it. Stir.
15. Fill the sixth glass one-third full of tap water. Add 2 drops of yellow food coloring and stir.
16. Using the turkey baster, draw up some of the saltwater (blue) and carefully place the tip of the baster into the very bottom of the glass with the yellow tap water.
17. **Very slowly**, squeeze the bulb of the baster so that the salty blue water comes out into the glass. Make a note of what happens.
18. Clean up and return everything to the proper place.

**CONCLUSION:** Write down what happened in the glasses with different temperatures and different salinities.

What happened in the experiment? In the first 2 glasses, the water had the same temperature and salinity. This is called the **control** of the experiment. It is important to see what happens to 2 samples of water with the same densities when they are moved around from one glass to another through the turkey baster. You should have seen the blue water coming up from the bottom and mixing with the yellow water. In the next part of the experiment, the cold, blue water should have mostly remained on the bottom of the glass with the warm, yellow water on top. Because of their temperature differences, the 2 colors of water remained separated, with the denser (cold) water on the bottom. This illustrates that colder temperatures make water denser. In the last part of the experiment, the blue saltwater also should have remained mostly separated from the tap water. Just like the cold water, it was denser and stayed on the bottom of the glass.

## *creation connection*

There are many processes in creation that bring salts into and out of the ocean. However, the rate at which salts enter the ocean (through rivers and volcanic discharge) is much higher than the rate at which salts leave the ocean (through salt spray and plate subduction). This means that the ocean is constantly increasing in salinity. Scientists have been studying this for several hundred years, and they know how quickly the amount of salts in the ocean has been increasing, or its rate of increase. With this information, they can calculate how long it took for today's oceans to get to their present salinities. Well, it turns out that it probably did not take very long. Calculations indicate that at most, it could take 40–60 million years for the oceans to reach their current salinity, and that is using very generous assumptions, including that the oceans *started out as freshwater seas.*[1] If we take into account that the oceans were most likely formed with some saltiness, due to the ease with which water dissolves minerals, the time required for the oceans to reach their present salinity is probably much, much shorter. Even a few million years is too young to support evolutionary theory, which claims the earth is billions of years old. Additionally, catastrophic events such as volcanic eruptions and rapid tectonic movement could rapidly increase salinities, shortening that estimation much more. The oceans themselves, then, are strong evidence that the earth is too young to support the process of evolutionary theory, despite what some scientists would have us believe.

[1]Austin, S. and R. Humphreys. 1990. The sea's missing salt: A dilemma for evolutionists. In *Proceedings of the Second International Conference on Creationism*, vol. 2. R. E. Walsh and C. L. Brooks, eds. Pittsburgh, PA: Creation Science Fellowship, 17-33; Sayles, F. and P. Mangelsdorf. 1979. Cation-exchange characteristics of Amazon with a suspended sediment and its reaction with seawater. *Geochimica et Cosmochimica Acta*. 43: 767-779.

As water gets saltier, its density increases. So the saltier and/or colder the water, the denser it is. Salinity and temperature, therefore, affect the density of water. In the ocean, we find that temperature has a greater influence on seawater density than does salinity because it has a greater range. Ocean temperatures can range from –2 °C to 40 °C, but open-ocean salinities vary by only a few parts per thousand.

Seawater also contains dissolved gases in addition to its dissolved solids. However, unlike solids, gases dissolve better in cold water than they do in warm water. So you will find higher concentrations of dissolved gases in polar waters versus tropical waters. Nitrogen, carbon dioxide, and oxygen are the most abundant of these gases. They are found in the earth's atmosphere and dissolve into seawater at its surface. Nitrogen gas is not involved in the basic life processes of most organisms, but carbon dioxide and oxygen play an active role. As you may remember from studying biology, carbon dioxide is used by producers such as plants and marine microorganisms for photosynthesis, making oxygen as a by-product. Most organisms utilize oxygen for respiration and produce carbon dioxide as a by-product. Marine life, therefore, depends upon dissolved gases in the ocean.

Now let's discuss how these parameters change in regard to ocean depths. There are some general statements that can be made about the vertical distribution of ocean temperature, salinity, and density. The densest seawater is found on the bottom of the ocean, but the physical processes that cause water to become more dense (such as evaporation and cooling) occur on the ocean surface. So dense water on the ocean bottom must have once been at the surface and then sunk to its present location. The main place this occurs is at the edge of ice sheets because ice formation excludes salt. Thus, cold, salty water forms in winter and sinks to the bottom of the ocean. This is the process that drives the circulation of water into the deep ocean basins.

Most of the oceans in creation are made up of 2 major layers. On top, there is a less-dense, well-mixed layer, warmed by the sun. This surface layer extends down to a point at which the sun can no longer warm the water and a rapid decrease in temperature occurs. Scientists call this feature a **thermocline**. Below this point is a layer of colder, denser water that remains very stable. Because the layers have different densities, the thermocline inhibits the mixing and exchange of nutrients and gases between the 2 layers. In some cases, it even prevents organisms from moving from one layer to the other. Even water over the continental shelf can have a thermocline, sometimes reaching into fairly shallow areas. Occasionally, in temperate waters, the thermocline can form in the summer and disappear in the winter, causing seasonal stratification and affecting algal populations.

Complete "On Your Own" question 1.9 before moving ahead.

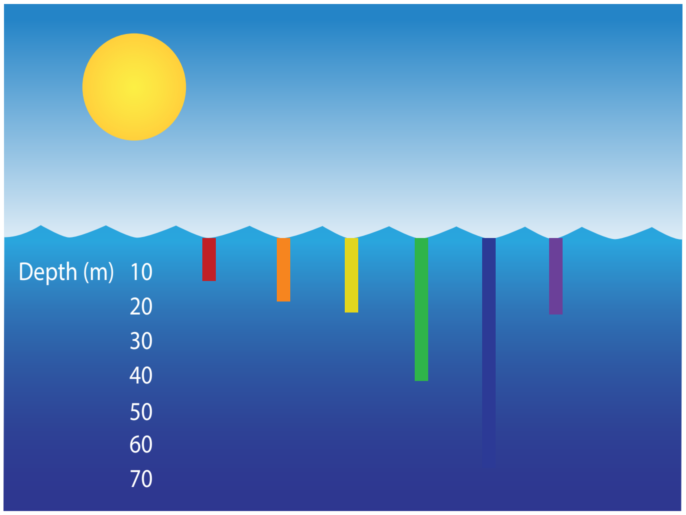
### ON YOUR OWN

1.9 If you were given a fish in a fish tank and were told to keep the salinity of the water very high and the temperature of the water very low to keep this fish healthy, what part of the ocean would you think was the natural habitat of this fish?

## LIGHT IN THE SEA

Now we get into one of the great questions of marine science: Why is the ocean blue? There is actually a very simple answer to this question. Visible sunlight is made up of different wavelengths of light that are perceived by our eyes as various colors. Different wavelengths (colors) of light penetrate transparent seawater to different depths, as shown in Figure 1.13.

**FIGURE 1.13**
**Light Penetration in Transparent Seawater**
Illustration by Colin Gunn




The ocean is most transparent to blue light, so the greater the depth, the fewer the colors that can penetrate, and the bluer the ocean appears. Also, the blue sky reflects off the surface of the ocean, enhancing its blue appearance. It's that simple!

All producers need light in order to make food for themselves, and the penetration of light into the ocean is vital for marine life. The amount of light that can enter the water depends upon the water's transparency. The more material suspended in the water, the more difficult it is for light to penetrate, and the fewer producers that can survive there.

Complete "On Your Own" question 1.10 before moving ahead.

## ON YOUR OWN

**1.10 The Red Sea is given its name due to the presence of reddish cyanobacteria that sometimes grow in high concentrations, giving the water a reddish color. When the cyanobacteria are not in high concentrations, what color should the Red Sea appear to be and why?**

### PRESSURE

There's one final aspect I want to talk about before we leave the topic of seawater. Organisms living in the ocean constantly experience pressure from the weight of the water above them. On land, pressure from the earth's atmosphere is 14.7 lbs per square inch, or 1 atmosphere. Pressure in the ocean increases dramatically with depth, so ocean creatures experience the weight of water above them as well as the air above the water. For every 10 meters (33 ft) of depth, another atmosphere of pressure is added. As the pressure increases, gases are compressed, affecting marine life. Because of this drastic pressure change, most marine organisms can tolerate only small changes in depth, limiting the range in which they are able to live. Most of the marine organisms with which you are familiar can survive at only 1 to 3 atmospheres of pressure, which means they can live in only the first 30 meters of water. At the same time, however, there are some organisms that have been designed to withstand the constant high pressure of the deep sea. The life cycles and habits of these creatures are relatively unknown because to study them, we must bring them to the surface, or at least to depths in which we can function. At the surface, their bodies cannot withstand the relatively small pressure, and they cannot survive. One such creature is the megamouth shark, as shown in Figure 1.14.

**FIGURE 1.14**
**A Megamouth Shark**
Photo copyright © Tom Haight

The megamouth shark lives in the deep waters of the ocean. Because these creatures rarely come to the surface, little is known about them. We think they live at depths between 150 and 1,000 meters. The inside of the shark's mouth is silvery, and its teeth are small and hook-like. Like the whale shark and the basking shark, the megamouth shark is a filter feeder, eating small shrimp and a variety of plankton. Adult megamouth sharks reach a length of about 5 meters.

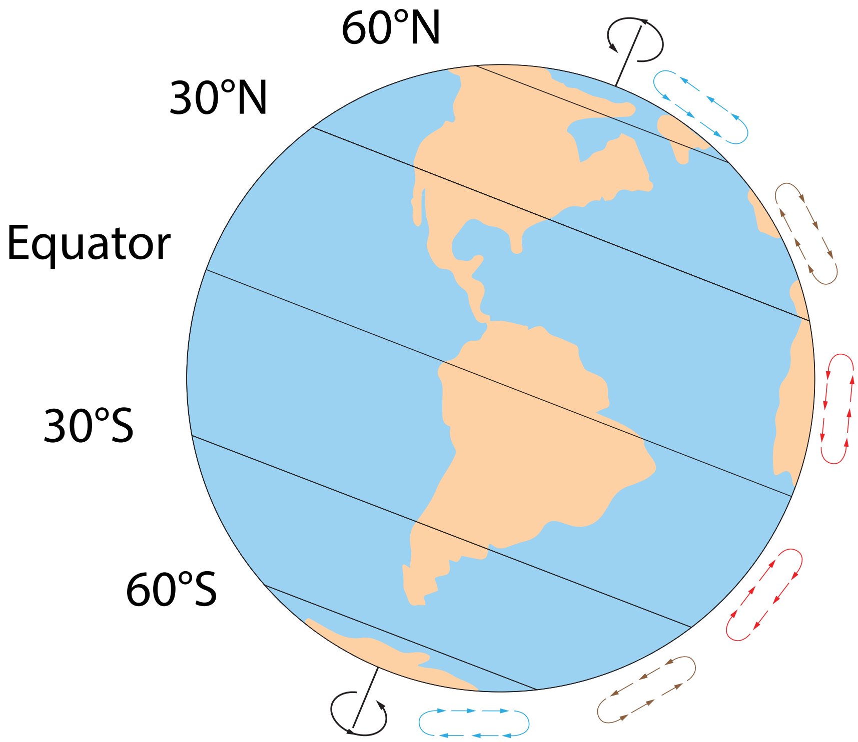
## THE MOTION OF THE OCEAN

The ocean is always in motion. This constant moving and churning helps keep the temperature and salinity of the world's oceans at a constant level. Heat from the sun drives these circulation processes, benefiting all marine life forms. These processes include currents, waves, and vertical water movements. The tides are also a part of the motion of the ocean, but they are not caused by heat from the sun. You will learn about them in a moment.

The strongest motion in the ocean occurs at its surface and is made up of surface currents and waves. Ocean surface currents are in regions where winds regularly blow over the ocean in a reasonably constant direction and velocity, pushing the water along. Surface currents, then, are large, horizontal movements of water molecules being pushed by the winds above them.

The winds in our atmosphere result from temperature differences caused by heat from the sun. The heat is its strongest at the equator and, of course, much weaker at the North and South Poles. To understand wind patterns, consider the dense cold air near the surface of the earth at the North Pole. As the air sinks, it moves from the North Pole toward the equator. As it makes its way there, however, it encounters a warmer climate. This warms the air, causing it to rise. When the air makes it to the 60°N latitude, it becomes so warm that it rises into the upper atmosphere and begins *moving back toward the pole!* In the end, this sets up a loop of winds that travel continuously from the pole to a latitude of about 60°N and back up again. This loop of winds is shown as the blue loop in Figure 1.15. A similar loop of winds extends northward from the South Pole.

**FIGURE 1.15**
**Global Wind Patterns**
Illustration by Colin Gunn



## creation connection

In the mid 1800s, Matthew Maury, a devout Christian, worked at the Depot of Charts and Instruments in the Hydrographic Office of the United States Navy. As he was reading Psalm 8:3–8 in his Bible, he noticed that the Bible mentioned "paths" of the seas. He was also aware of Ecclesiastes 1:6, which mentions circuits of the wind around the earth. Recognizing the value this would have for marine navigators, he found and plotted the wind circuits and the ocean currents!

Gish, D. 1991. Modern Scientific Discoveries Verify the Scriptures. *Acts & Facts*. 20 (9).

If we turn our attention to the equator, we will see the exact opposite effect. As the warm air rises, it starts traveling toward the poles. At latitudes of about 30°N and 30°S, however, it cools down enough to sink and begin traveling back toward the equator. Thus, from the equator, there are also 2 loops of winds that travel to latitudes of about 30°N and 30°S, and then turn around and come back again. This phenomenon is represented by the red loops of wind in the figure. In the middle of these 2 loops of wind there is a third loop (the brown loop) that occurs as a reaction to these 2 loops. The result of all this mess is shown in Figure 1.15.

This is not the end of the story, however. The winds don't move straight as shown in Figure 1.15. They actually *curve*. To understand this curving of winds, perform Experiment 1.4.

## EXPERIMENT 1.4
### THE CORIOLIS EFFECT

**PURPOSE:** To understand how atmospheric winds move due to the earth's rotation

**MATERIALS:**
- 1 sheet of cardstock
- Scissors
- A tack or pushpin
- 1 foot of string
- A pencil
- A cork bulletin board or sheet of corrugated cardboard
- A marker
- A helper

**QUESTION:** Why do winds on the earth move in curved directions?

**HYPOTHESIS:** Write down your hypothesis about what will happen when wind moves in a straight direction along the earth.

**PROCEDURE:**

1. Cut a circle about 6-7 inches in diameter out of card stock. To do this, tie a loop on one end of the string and push the tack through it into the center of the card stock and into the bulletin board.
2. Tie the pencil to the other end of the string and pull it taut.
3. Draw a circle on the card stock by moving the pencil along in a circular motion while continuing to keep the string taut.
4. Remove the card stock from the bulletin board and cut the circle out with the scissors.
5. Replace the circle back onto the bulletin board, affixing it through the center with the tack, but not so tightly that it cannot revolve.
6. Draw an arrow along the outside edge of the circle that points in a clockwise direction.
7. Have your helper stand on your right side and place his finger at the 9 o'clock position on the circle. Meanwhile, place the marking pen at the center of the circle.
8. At the same time, have your helper begin to slowly spin the circle in a clockwise direction while you slowly try to draw a straight line downward.
9. Remove the circle and note whether the line you drew moved straight down, clockwise (with the rotation), or counterclockwise (opposite of the rotation).
10. Clean up and return everything to the proper place.

**CONCLUSION:** Write something about what happened in the experiment.

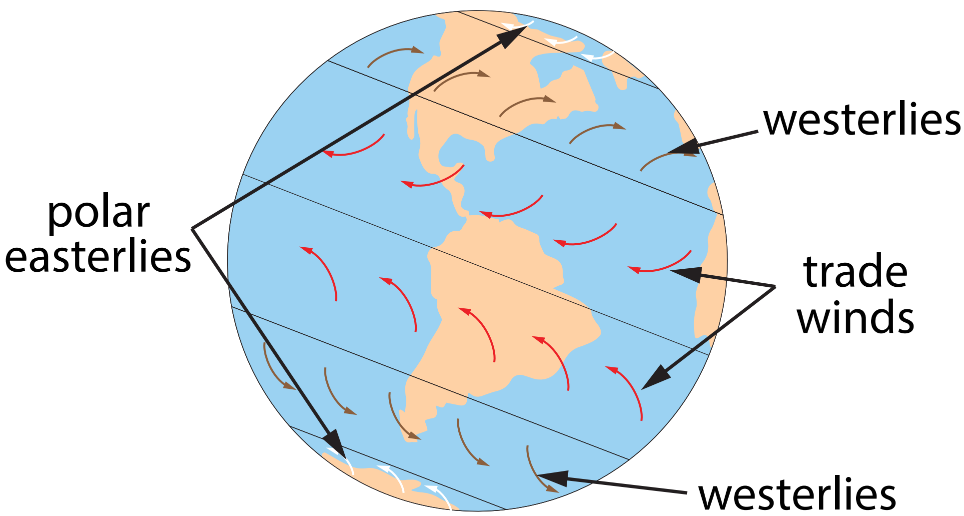
What happened in the experiment? When you tried to draw a straight line toward the lower edge, it should have curved. Notice the *direction* in which it curved. It moved *away from* the direction of the rotation of the wheel. That's what happens on the earth. The winds moving toward the equator curve in a direction opposite of the rotation of the earth. Scientists call this phenomenon the **Coriolis** (cor ee oh' lis) **effect** after the French physicist Gaspard de Coriolis.

**Coriolis effect**—The way in which the rotation of the earth bends the path of winds and resulting sea currents

Consider the winds nearest the equator. They are pictured by the red loops in Figure 1.15. We are going to concentrate on the winds that blow near the surface of the earth because those are the winds that blow on the ocean. So just look at the bottom of each loop in Figure 1.15. In the red loops, the winds blowing near the surface of the earth are moving toward the equator. Because of the Coriolis effect, these winds bend west (opposite the rotation of the earth) and approach the equator at an angle of about 45°. These winds (shown in Figure 1.16) are called the **trade winds** and are the most consistent winds on earth. Farther away from the equator are the brown loops of winds shown in

Figure 1.15. The winds near the surface of the earth on these loops are bent opposite the trade winds because they are traveling away from the equator instead of toward it. Thus, the Coriolis effect causes them to bend in the opposite way. These winds are called the westerlies (shown in Figure 1.16). They are more variable than the trade winds due to many land interruptions. Scientists call these winds westerlies because they move in the opposite direction from the trade winds and come from the west. The northernmost and southernmost winds are called the polar easterlies and are the most variable winds of all. They curve in the same direction as the trade winds since they once again move toward the equator near the surface of the earth.

**FIGURE 1.16**
**Major Atmospheric Wind Fields**
Illustration by Colin Gunn




Now all these major wind fields in the atmosphere push against the ocean surface and create currents. In fact, you could say that all the major currents of the open ocean are driven by the wind. As the wind pushes against the ocean surface, it causes the water to move. When the wind moves the water, it forces the surface currents to move at a 45° angle from the wind direction. The equatorial trade winds being bent from the Coriolis effect, for example, cause the currents below them to move parallel to the equator. As water gets pushed around all over the world, large surface currents result in a circular pattern. Scientists call these currents gyres (jires), and they are outlined in Figure 1.17.

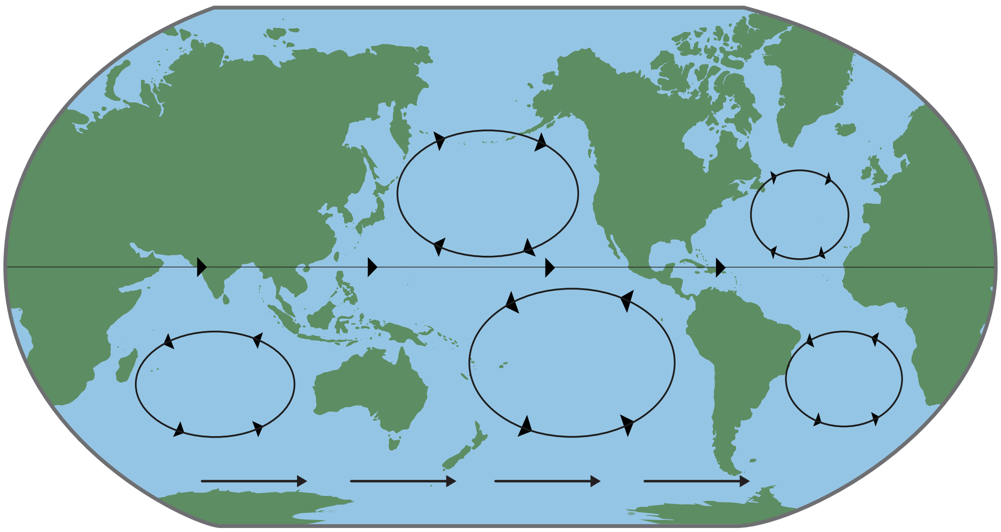
## *think about this*

In some parts of the world, there are major ocean current systems that can spin off whirlpools. These vortexes can last for several months and will pull anything caught in their path. Ocean whirlpools, usually called ocean eddies, can be hundreds of miles across and contain billions of tons of swirling water. Most are not very powerful. On the other extreme, a strong tidal current, called the Saltstraumen Maelstrom, exists near the Arctic Circle on the coast of Norway. It is said to be one of the world's strongest and throws off whirlpools powerful enough to be a threat to small boats.

**Gyres**—Large, mostly circular systems of surface currents driven by the wind

The warm-water currents on the western side of the gyres of the world carry a lot of solar heat from the equator to higher latitudes. The opposite is true too: cold currents flow along the eastern sides of the oceans, bringing colder water to the equatorial areas. This movement helps to regulate the temperatures of our planet, keeping the cold and hot temperatures from becoming extreme.

**FIGURE 1.17**
**Map of the Earth Showing Major Surface Currents and Gyres of the Ocean Basins**
Illustration by Colin Gunn



The temperature of the sea surfaces of the world is also a result of this circulation. Along the Pacific coast of the United States and the western coast of South America, the colder water temperatures are the result of gyres. Look at the loops of current on the west coasts of North and South America. On the west coast of North America, the current loop carries water from near the Arctic (cooler water) southward. On the west coast of South America, the loop of current carries water from near the Antarctic (cooler water) northward. As a result, the ocean water is cooler on the west coasts of North and South America. Because of this, cold-water organisms can survive closer to the equator on these coasts than in other parts of the world. Conversely, warm-water organisms can survive farther from the equator on the eastern coast of Asia because the gyres bring warm water from near the equator to parts of the ocean far from the equator.

Complete "On Your Own" questions 1.11–1.12 before moving ahead.

## ON YOUR OWN

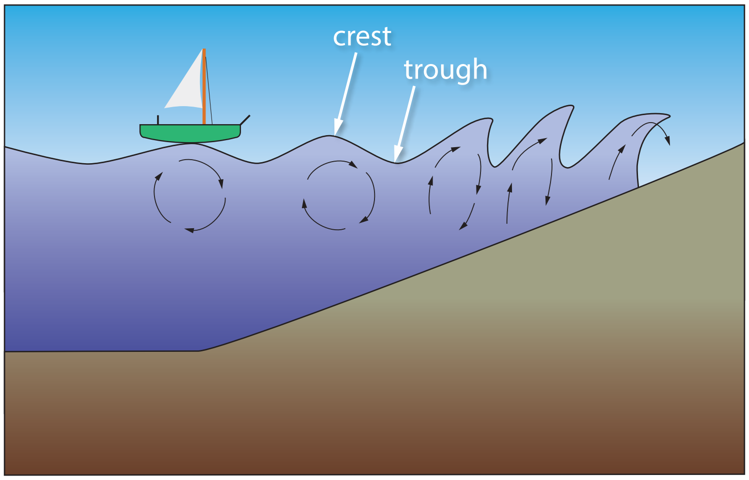
1.11 During a terrible storm on the west coast of South America, a boat loses a box of its cargo of rubber ducks. One of the ducks is found in Japan months later. How did it get there?

1.12 Suppose you were looking for coral reefs (which love warm water) in the Atlantic Ocean relatively far from the equator. Would you tend to find them on the eastern coast of North America or the western coast of Europe?

## WAVES

Now let's talk about the most familiar of ocean movements: waves. You are probably well acquainted with the motion of waves, as they can be observed in a bowl of water or a bathtub. What you may not realize, however, is that each individual water molecule does not actually move along with the wave crest as it travels. The water molecules actually move in a circle. In Figure 1.18, a toy boat resting on the water's surface will move mostly up, around, down, and back up again as a series of waves pass by. Remember, I'm not talking about currents, in which water is getting pushed along; I am just talking about waves.

**FIGURE 1.18**
**Waves Forming at the Shoreline**
Illustration by Colin Gunn




Perform Experiment 1.5 to observe this for yourself.

## EXPERIMENT 1.5
### THE MOTION OF WAVES

**PURPOSE:** To observe the motion of water molecules in a surface wave

**MATERIALS:**
- A bathtub
- Water
- A cork or small toy boat
- A 12-inch length of 2-by-4 wood

**QUESTION:** How do water molecules move within a surface wave?

**HYPOTHESIS:** Write down your hypothesis about what will happen to a cork when it encounters surface waves.

**PROCEDURE:**

1. Fill the bathtub with water until the water is about 3 inches deep.
2. Place the cork or boat in the very center of the tub.
3. Place the length of wood about halfway down into the water at the end of the tub near the spigot so that its longest side is in the water, perpendicular to the length of the tub.
4. Gently but steadily move the plank about 10 times up and down. Move it about ½-1 inch in each direction, and keep it at the end of the tub. Do not let it splash! This should create a series of parallel waves moving down the length of the tub toward the cork. Observe the cork's position in the tub while you do this.
5. Allow the water to become still again. Reposition the cork, and repeat the experiment a few more times.
6. Clean up and return everything to the proper place.

**CONCLUSION:** Write something in your notebook about what happened to the cork when it encountered waves.

In the experiment, the cork should have bobbed up and down only as the crests of waves came by. That's because waves carry energy across the sea surface. They do not actually transport water. As a result, the cork moved up and down with the individual water molecules, and the energy continued past.

Waves entering shallow water behave differently than open-ocean waves. Look again at the diagram in Figure 1.18. As the water becomes shallower, the sandy surface interrupts the circular motion of the waves, slowing down the underside as it drags across the bottom. This causes the faster water above to pile up behind the top of the wave. Eventually, the wave becomes so high and steep that the wave top falls forward and breaks against the shore, creating surf.

## TIDES

Another aspect of ocean water movement is the tides. Tides greatly impact sea life near shore. They are so regular that many animals have reproductive cycles that coincide with them. The forces that create ocean tides are outside our normal daily experience and so it can be a bit difficult to explain them.

A good way to understand what is going on is to take an imaginary planet and place it in space near a star. The planet will immediately start falling toward the star due to gravity. But the attractive force from the star is stronger on the near side of the planet than the far side. That means the edge of the planet on the *near* side should accelerate faster than the edge on the *far* side. But planets like ours are made of rock. They hold together despite the stress of having one side pulled more than the other. Therefore, the planet is pulled toward the sun according to its *average* distance to the star. If we cover that planet in water (similar to the earth), the water on the near side will literally fall toward the star faster than the planet will. At the same time, the water on the far side will not fall toward the star as fast as the planet beneath it. The result is that we will get a tidal bulge on the near side and an equal-sized tidal bulge on the far side, just like what we see on earth.

However, the earth is not falling into the sun—we are moving forward at the same time we are falling, resulting in a nearly circular orbit. But our forward movement does not negate the force of gravity from the sun. You see, points on the earth's surface react to the sun's gravity *in the same way as if we were falling straight toward it*. So there should be 2 tidal bulges on the earth caused by the sun's gravity (and, indeed, there are).

We can explain lunar tides in exactly the same way. The moon and the earth are constantly attracting each other. They are literally falling toward one another. But the water on the near side of the earth falls toward the moon faster than the water on the far side. And even though the sun is much more massive, the moon is much closer. The result is that the lunar tide is about twice that of the solar tide.

Of course, water does not stretch and cannot lift off the bottom of the ocean, so why does the water bulge up? The water that adds to the bulges comes from the places on earth where the net gravitational forces are near-parallel to the earth's surface (Figure 1.19). Here, the water slides sideways just a little as it falls faster toward the moon on the near side, or falls more slowly than the rest of the earth on the far side.

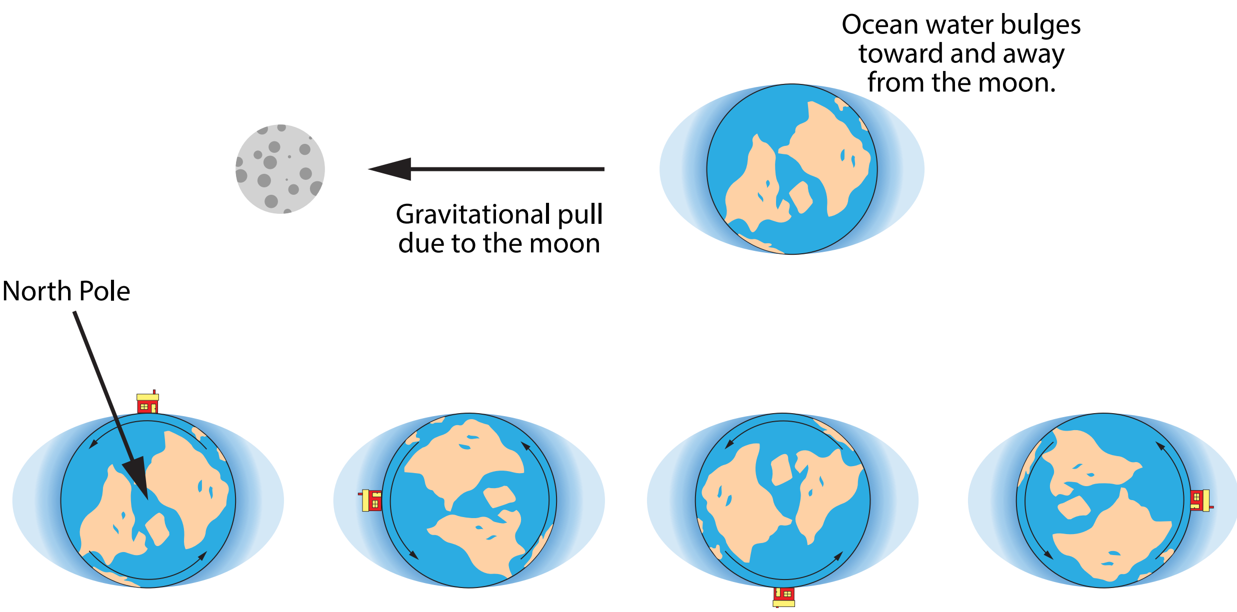
This is what causes oceanic tides, as first explained by Sir Isaac Newton in 1687. However, tides are more complex than in this simple illustration because as the water bulges move across the surface they run into shallower water (which changes their speed) and irregular coastlines (which create complex patterns of water flow). The result is that some places experience regular, twice-daily high tides, some places experience once-daily high tides, some places experience extreme tides, and some places have virtually no tides at all.

Add to this the fact that the sun and moon are not in phase. Solar tides occur twice every day, but the lunar day is 24 hours and 50 minutes long. When the solar and lunar tides are lined up, we experience above-average **spring tides**. (They occur every 2 weeks, not just in the spring!) When they are opposite one another, we have below-average **neap tides**.

**Spring tide**—A time of largest tidal range due to the gravitational pull of the aligned sun and moon (during full moon and new moon)

**Neap tide**—A time of smallest tidal range due to the moon and sun being located at right angles to each other (during quarter moons)

**FIGURE 1.19**
**Diagram of the Ocean's Bulge Due to the Moon**
Illustration by Colin Gunn




In the lower diagram, when a specific point on the earth (such as the house) rotates through a full 24-hour day, 2 high tides and 2 low tides are experienced. In the drawing on the far left, the house is experiencing low tide. The second drawing shows the house later on in the day when it is experiencing high tide. The third drawing shows the house experiencing low tide even later in the day, and the fourth drawing shows the house experiencing high tide at an even later time during the same day.

Complete "On Your Own" questions 1.13–1.14 before moving ahead.

### ON YOUR OWN

1.13 If the moon were farther from the earth, what change would you expect in high tide and low tide?

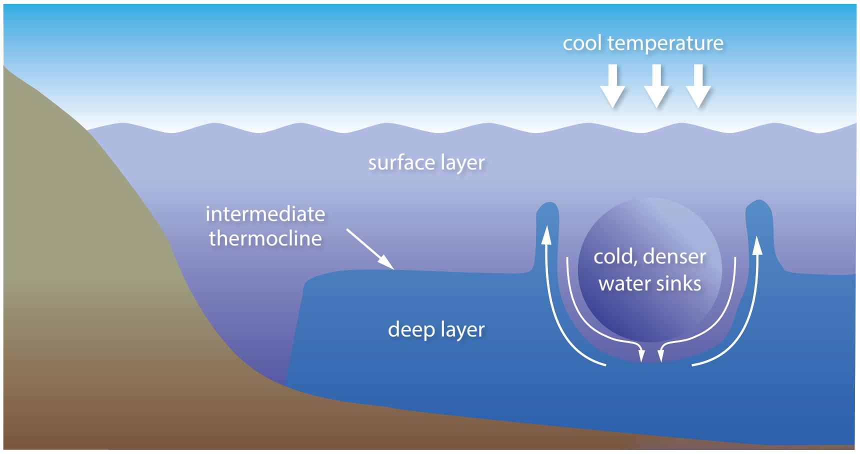
1.14 A man living at the beach looks out his window and sees a full moon. What type of high tides can he expect in the next few days?

## VERTICAL MOTION

I want to talk about one more way ocean water can move. It has to do with vertical movement and the density of seawater. As I mentioned before, the ocean has 2 main layers, separated by a thermocline. The thermocline can be considered a third layer between the upper and lower ones. The **surface layer** is about 100–200 meters (330–660 ft) thick. It is subjected to wind, waves, and currents, so it is usually well mixed. The **thermocline** is a zone about 200–1,500 meters (660–5,000 ft) deep. It is a transitional zone where the temperature drops rapidly, between the warmer layer on top and colder layer below. Generally, it is found in the open ocean, away from the continental-shelf areas. Below the thermocline is the **deep layer**, which is uniformly cold and thus more dense than the surface layer.

A group of water layers like this is called a **water column**. Deep water is mostly cold and dense, and surface water is warm and less dense. Usually, these layers will stay where they are and will not mix unless a storm or strong wind stirs them up. A water column such as this is highly stable due to the differing densities of its layers. When the layers' densities are not very different from one another, however, it is much easier for them to mix. Scientists call this situation a **low-stability water column**. In a low-stability water column, the surface water can become denser by excess evaporation or cooler due to seasonal temperatures. The surface water sinks, displacing the less-dense water below in a process called **overturn** depicted in Figure 1.20.

**FIGURE 1.20**
**The Process of Overturn**
Illustration by Colin Gunn




Cool winter temperatures cause the water temperature of the surface layer to become colder, so there is no longer a density difference between the surface and deep waters. It is able to sink and more easily mixes with the deep layer, displacing the same amount of water, which, in turn, moves upward.

### ON YOUR OWN

**1.15 Would you expect to see greater overturn in the winter or summer months?**

Overturn benefits the ocean because sinking surface water brings dissolved oxygen to the deep sea. In addition, the rising water replacing the upper water brings nutrient-rich material to the surface for use by the organisms living there.

Complete "On Your Own" question 1.15 before moving ahead.

## SUMMING UP

In this first module, I have covered many aspects of the physical features of the ocean. You have learned about the geography and placement of the world's oceans, features of the ocean bottom, properties of seawater, and how seawater moves around the world. This information will help as you study marine organisms because you now understand many of the conditions under which they must survive.

## ANSWERS TO THE "ON YOUR OWN" QUESTIONS

1.1 The 4 major ocean basins of the world are the Pacific Ocean basin, the Atlantic Ocean basin, the Indian Ocean basin, and the Arctic Ocean basin. The fifth ocean is the Southern Ocean.

1.2 Since the crusts are composed of different chemicals, you could chemically test for basalt or granite. The granite-containing sample is from continental crust, while the basalt-containing sample is from oceanic crust. Alternatively, since oceanic crust is denser than continental crust, you could measure their densities. The denser sample is from oceanic crust.

1.3 No, but this find would be *evidence* that supports the idea that the land masses of the world were once connected. To *prove* it was true, there would have to be documentation from eyewitnesses. Note: Such fossil discoveries have actually been made!

1.4 It would most likely be far from a mid-ocean ridge. Seafloor is created at the mid-ocean ridges and is newer than the seafloor farther away from the ridges. The older floor has more time to collect sediment than the newer floor.

1.5 The oceanic plate will sink into the mantle, forming a trench and continental volcanoes. Oceanic plate material is denser than continental plate material and therefore will sink below it.

1.6 It most likely came from the continental rise. That is where a lot of debris and sediment build up.

1.7 Hydrogen bonding gives water many unusual properties.

1.8 It will sink. Since water is the only readily available chemical that is denser in its liquid phase than its solid phase, it is the only substance in which the solid phase floats on the liquid phase. All other readily available substances are denser in their solid phase, so solid benzene will sink in liquid benzene.

1.9 This fish probably lived in a deep ocean environment. Colder water with a high salinity would mean denser-than-average conditions, and therefore it would be located below the other layers of seawater.

1.10 The Red Sea would appear blue due to the water being most transparent to blue light and also the reflection of the blue sky.

1.11 The duck would have traveled north along the cold current coming up from the Antarctic waters. It then would have traveled a bit east along the equator; but once it crossed the equator, it would have floated north and west with the warm equatorial current moving up into the Northern Hemisphere until it reached Japan. NOTE: An ocean spill of a shipment of rubber ducks actually occurred in 1972 in the Pacific Ocean. Ducks were subsequently found up to 15 years later all over the world, having followed the gyres of the oceans!

1.12 Look at Figure 1.17. The gyre found in the Northern Hemisphere of the Atlantic Ocean carries water from near the equator to the eastern coast of North America. As a result, the water there is relatively warm. That same gyre, however, brings water from near the Arctic to the western coast of Europe. Thus, you would be more likely to find coral on the eastern coast of North America.

1.13 The moon's gravitational pull has the most influence on the earth's tides. If the moon were farther away from the earth, its gravitational pull would be smaller (and many other problematic issues would be created!). As a result, the tides would not be as extreme. Thus, high tide would be lower and low tide would be higher.

1.14 He can expect to see much higher high tides than average (spring tides). This is because of the spring-tide phenomenon where the gravitational pulls from the moon and the sun work together.

1.15 Greater overturn would occur in the winter months. As the warmer surface water cools due to the winter temperatures, it becomes denser and will therefore sink. In the summer months, the surface layer gets warmer, making it even less dense. As a result, it will not sink into the deeper water.

# STUDY GUIDE FOR MODULE 1

1. Define the following terms:
   a. Oceanic crust
   b. Continental crust
   c. Plate tectonics
   d. Mid-ocean ridge
   e. Seafloor spreading
   f. Subduction
   g. Continental shelf
   h. Continental slope
   i. Continental rise
   j. Specific heat
   k. Salinity
   l. Coriolis effect
   m. Gyres
   n. Spring tide
   o. Neap tide
2. Name the 4 large ocean basins of the world, in order of increasing size.
3. Geologically speaking, what are the differences between the crust of the oceans and the crust of the continents?
4. If a specific location in the world is known for experiencing a large number of earthquakes throughout modern history, what would you propose is occurring in the earth's crust underneath that area?
5. Given that most of the deep-ocean trenches in creation are located in the Pacific Ocean, what is the main type of plate interaction that occurs in that ocean?
6. Ocean crust is constantly being destroyed and reformed. Considering the 4 large ocean basins in the world, which ocean has the most oceanic crust formation? Which has the most oceanic crust destruction?
7. Although there is a large surface area under the oceans of the earth, in which main region of the ocean bottom is most of the marine life?
8. What one major property of water helps it hold its molecules together, keeping it from having severely colder boiling and freezing temperatures?
9. If a marine organism lives in an area where there are drastic changes in the weather resulting in extremely high and low air temperatures, what property of water prevents the organism from feeling such changes?
10. What will happen to the water near the ocean surface if a portion of the surface layer experiences excess evaporation? What will happen if that portion experiences a large drop in temperature?
11. Why is the ocean blue?

12. A fisherman was deep-sea fishing and pulled up a large bottom-dwelling grouper he had hooked. He was able to bring the fish up to the surface very quickly, but was surprised to see that the fish appeared extremely bloated (puffed up) and did not survive the stress of coming to the surface. What happened?

13. Why do winds not move in a straight line on the earth?

14. Suppose the earth rotated opposite of the direction it currently rotates. What effect would that have on the directions of the gyres shown in Figure 1.17?

15. Where do water molecules move in a surface wave?

16. During which phase (or phases) of the moon are the tidal ranges the largest and why?

17. Describe the 2 major layers of the deep ocean and the feature that separates them.