HS Earth's Oceans

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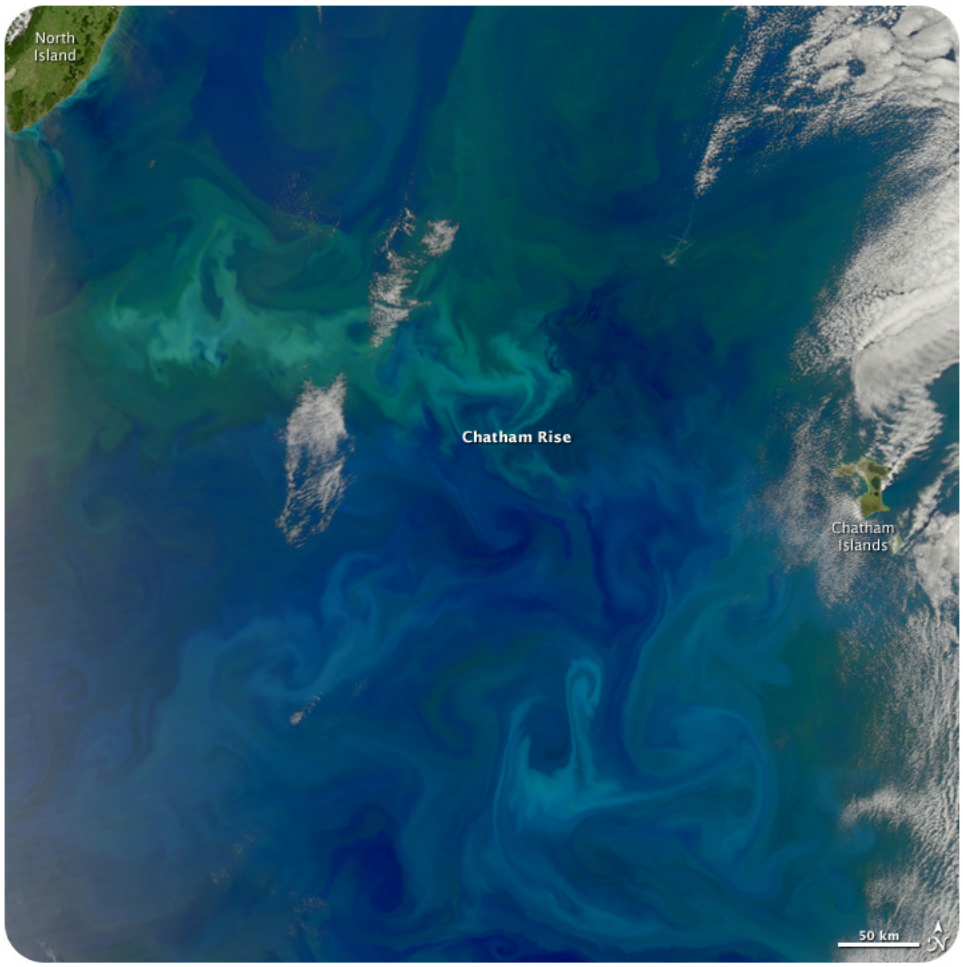
CHAPTER 1 HS Earth's Oceans

CHAPTER OUTLINE



Phytoplankton bloom in spring when sunlight hits the water. The green color is from chlorophyll, the pigment needed for photosynthesis. The blue color is from the reflective plating around coccolithophores, a type of phytoplankton. The Chatham Rise is an underwater plateau that causes deep water to rise, bringing up nutrients. The feature is located where cold Antarctic currents meet warmer, subtropical water. The mixing of water and the nutrients foster large phytoplankton blooms.

Phytoplankton are the base of the marine food web and so they are food to nearly all other marine organisms. By using carbon dioxide for photosynthesis, phytoplankton help to reduce the buildup of greenhouse gases in the atmosphere.

1.1 Introduction to the Oceans

Lesson Objectives

- Explain the significance of the oceans.
- Describe the composition of ocean water.
- Define the parts of the water column and oceanic divisions.

Vocabulary

- aphotic zone
- biomass
- intertidal zone
- neritic zone
- oceanic zone
- photic zone
- salinity
- water column

Introduction

As terrestrial creatures, humans think of the importance of the planet's land surfaces. But Earth is mostly a water planet. From space, the dominance of water is obvious (**Figure** 1.1). Most of Earth's water is in the oceans.

Because all of Earth's oceans are somehow connected, should this chapter be titled "Earth's Ocean" or "Earth's Oceans?" Try to decide by the end of the chapter.

An animation will help you see Earth's one, three, four, or five oceans: http://en.wikipedia.org/wiki/File:World_ocean_map.gif.

Significance of the Oceans

Earth would not be the same planet without its oceans.

Moderates Climate

The oceans, along with the atmosphere, keep temperatures fairly constant worldwide. While some places on Earth get as cold as -70°C and others as hot as 55°C, the range is only 125°C. On Mercury temperatures go from -180°C to 430°C, a range of 610°C.

The oceans, along with the atmosphere, distribute heat around the planet. The oceans absorb heat near the equator and then move that solar energy to more polar regions. The oceans also moderate climate within a region. At the same latitude, the temperature range is smaller in lands nearer the oceans than away from the oceans. Summer temperatures are not as hot, and winter temperatures are not as cold, because water takes a long time to heat up or cool down.

FIGURE 1.1
About 71% of the Earth

Water Cycle

The oceans are an essential part of Earth's water cycle. Since they cover so much of the planet, most evaporation comes from the ocean and most precipitation falls on the oceans.

Biologically Rich

The oceans are home to an enormous amount of life. That is, they have tremendous biodiversity (**Figure** 1.2). Tiny ocean plants create the base of a food web that supports all sorts of life forms. Marine life makes up the majority of all biomass on Earth. (**Biomass** is the total mass of living organisms in a given area.) These organisms supply us with food and even the oxygen created by marine plants.

Continental Margin

Recall from the Plate Tectonics chapter that the ocean floor is not flat: mid-ocean ridges, deep sea trenches, and other features all rise sharply above or plunge deeply below the abyssal plains. In fact, Earth's tallest mountain is Mauna Kea volcano, which rises 10,203 m (33,476 ft.)meters) from the Pacific Ocean floor to become one of the volcanic mountains of Hawaii. The deepest canyon is also on the ocean floor, the Challenger Deep in the Marianas Trench, 10,916 m (35,814 ft).

The continental margin is the transition from the land to the deep sea or, geologically speaking, from continental crust to oceanic crust. More than one-quarter of the ocean basin is continental margin. (**Figure** 1.3).

FIGURE 1.2
A swimming polar bear is a tiny part of the immense biodiversity of the oceans.

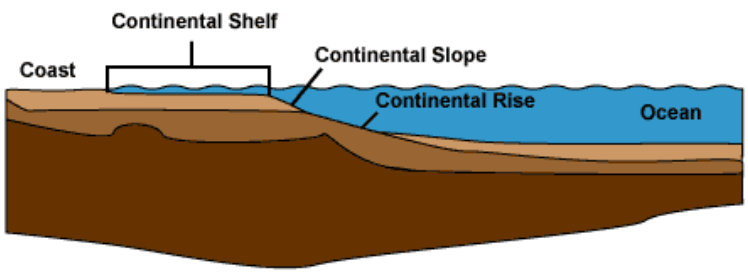


FIGURE 1.3
The continental margin is divided into the continental shelf, continental slope, and continental rise, based on the steepness of the slope.

Composition of Ocean Water

Remember from the Mineral's chapter that H_2O is a polar molecule so it can dissolve many substances (**Figure** 1.4). Salts, sugars, acids, bases, and organic molecules can all dissolve in water.

Where does the salt in seawater come from? As water moves through rock and soil on land it picks up ions. This is the flip side of weathering. Salts comprise about 3.5% of the mass of ocean water, but the salt content or **salinity** is different in different locations.

What would the salinity be like in an estuary? Where seawater mixes with fresh water, salinity is lower than average.

What would the salinity be like where there is lots of evaporation? Where there is lots of evaporation but little circulation of water, salinity can be much higher. The Dead Sea has 30% salinity—nearly nine times the average salinity of ocean water (**Figure** 1.5). Why do you think this water body is called the Dead Sea?

Interactive ocean maps can show salinity, temperature, nutrients, and other characteristics: http://earthguide.ucsd.edu/earthguide/diagrams/levitus/index.html.

With so many dissolved substances mixed in seawater, what is the density (mass per volume) of seawater relative to fresh water?

Water density increases as:

- salinity increases
- temperature decreases

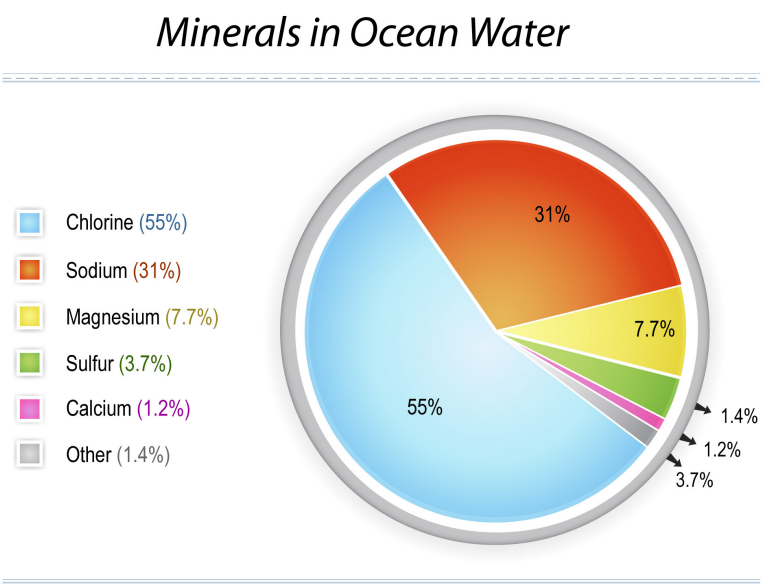


FIGURE 1.4
Ocean water is composed of many substances, many of them salts such as sodium, magnesium, and calcium chloride.

FIGURE 1.5
The Dead Sea has such high salinity that people can easily float in it.

- pressure increases

Differences in water density are responsible for deep ocean currents, as will be discussed in the Ocean Movements lesson.

The Water Column

In 1960, two men in a specially designed submarine called the Trieste descended into a submarine trench called the Challenger Deep (10,910 meters) (**Figure** 1.6).

The average depth of the ocean is 3,790 m, a lot more shallow than the deep trenches but still an incredible depth for sea creatures to live in. What makes it so hard to live at the bottom of the ocean? The three major factors that make the deep ocean hard to inhabit are the absence of light, low temperature, and extremely high pressure.

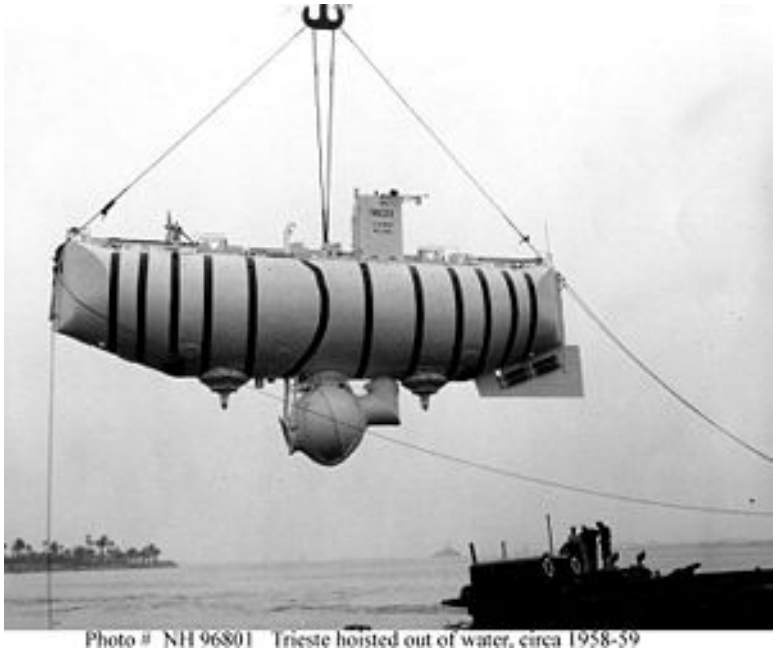


FIGURE 1.6
The Trieste made a record dive to the Challenger Deep in 1960. No craft exists today that can reach that depth.

Vertical Divisions

To better understand regions of the ocean, scientists define the **water column** by depth. They divide the entire ocean into two zones vertically, based on light level. Large lakes are divided into similar regions.

- Sunlight only penetrates the sea surface to a depth of about 200 m, creating the **photic zone** (photic means light). Organisms that photosynthesize depend on sunlight for food and so are restricted to the photic zone. Since tiny photosynthetic organisms, known as phytoplankton, supply nearly all of the energy and nutrients to the rest of the marine food web, most other marine organisms live in or at least visit the photic zone.
- In the **aphotic zone** there is not enough light for photosynthesis. The aphotic zone makes up the majority of the ocean, but has a relatively small amount of its life, both in diversity of type and in numbers. The aphotic zone is subdivided based on depth (**Figure** 1.7).

Horizontal Divisions

The seabed is divided into the zones described above, but ocean itself is also divided horizontally by distance from the shore.

- Nearest to the shore lies the **intertidal** (littoral) **zone**, the region between the high and low tidal marks. This hallmark of the intertidal is change: water is in constant motions in waves, tides, and currents. The land is sometimes under water and sometimes is exposed.
- The **neritic zone** is from low tide mark and slopes gradually downward to the edge of the seaward side of the continental shelf. Some sunlight penetrates to the seabed here.
- The **oceanic zone** is the entire rest of the ocean from the bottom edge of the neritic zone, where sunlight does not reach the bottom. The sea bed and water column are subdivided further, as seen in the figure above.

Lesson Summary

- The oceans help to moderate Earth's temperatures.

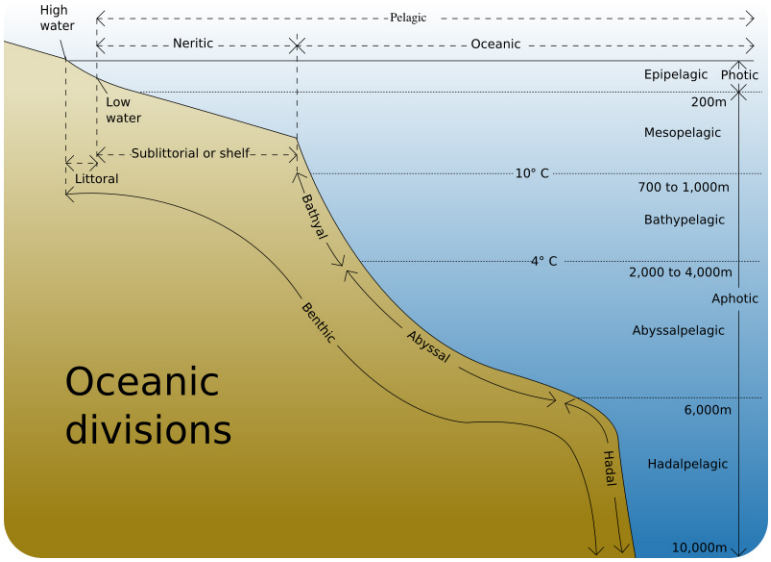


FIGURE 1.7

Oceanographers divide the ocean into zones both vertically and horizontally.

- The main elements in seawater are chlorine, sodium, magnesium, sulfate, and calcium.
- The average salinity of the oceans is about 3.5%.
- In seawater, if evaporation is high, salinity is high. If fresh water mixes in, salinity is low.
- In the photic zone there is enough available light for photosynthesis.
- The vast majority of the ocean lies in the aphotic zone, where there is not enough light for photosynthesis.
- The ocean floor averages about 3,790 m but ocean trenches are as deep as 10,910 m.
- The neritic zones are nearshore areas, including the intertidal zone. The oceanic zones are offshore regions of the ocean.

Review Questions

1. What percent of the Earth's surface is covered by water?
2. How do the oceans help to moderate Earth's temperatures?
3. What is the most common substance that is dissolved in ocean water?
4. Define density. Why is density important to the water column?
5. Compare and contrast the photic and aphotic zones.
6. Briefly describe the types of organisms found in the intertidal, neritic, and oceanic zones.

Points to Consider

- How do water motions such as tides and waves affect living creatures in and near the sea?
- Is it possible to have a river in the middle of the ocean?
- What factors affect the movement of ocean water? How do these factors affect the world's climate and the ocean's ecosystem?

1.2 Ocean Movements

Lesson Objectives

- Define waves and explain their formation.
- Describe what causes tides.
- Describe how surface currents form and how they affect the world's climate.
- Describe the causes of deep currents.
- Relate upwelling areas to the food chain.

Vocabulary

- Coriolis effect
- downwelling
- gyre
- high tide
- longshore current
- low tide
- neap tide
- rip current
- spring tide
- storm surge
- surface current
- thermohaline circulation
- tidal range
- tide
- upwelling
- wave

Introduction

Ocean water is constantly in motion: north-south, east-west, alongshore, and vertically. Seawater motions are the result of waves, tides, and currents (**Figure** 1.8). Ocean movements are the consequence of many separate factors: wind, tides, Coriolis effect, water density differences, and the shape of the ocean basins. Water movements and their causes will be discussed in this lesson.

Waves

Waves have been discussed in previous chapters in several contexts: seismic waves traveling through the planet, sound waves traveling through seawater, and ocean waves eroding beaches. Waves transfer energy and the size of a wave and the distance it travels depends on the amount of energy that it carries.

FIGURE 1.8
Ocean waves transfer energy through the water over great distances.

Wind Waves

This lesson studies the most familiar waves, those on the ocean's surface. Ocean waves originate from wind blowing – steady winds or high storm winds - over the water. Sometimes these winds are far from where the ocean waves are seen. What factors create the largest ocean waves?

The largest wind waves form when the wind

- is very strong
- blows steadily for a long time
- blows over a long distance

The wind could be strong, but if it gusts for just a short time, large waves won't form.

Wind blowing across the water transfers energy to that water. The energy first creates tiny ripples that create an uneven surface for the wind to catch so that it may create larger waves. These waves travel across the ocean out of the area where the wind is blowing.

Remember that a wave is a transfer of energy. Do you think the same molecules of water that starts out in a wave in the middle of the ocean later arrive at the shore?

Water molecules in waves make circles or ellipses (**Figure** 1.9). Energy transfers between molecules but the molecules themselves mostly bob up and down in place.

In this animation, a water bottle bobs in place like a water molecule: http://www.onr.navy.mil/focus/ocean/motion/waves1.htm

An animation of motion in wind waves from the Scripps Institution of Oceanography: http://earthguide.ucsd.edu/earthguide/diagrams/waves/swf/wave_wind.html

An animation of a deep water wave is seen here: http://en.wikipedia.org/wiki/File:Deep_water_wave.gif.

An animation of a shallow water wave is seen here: http://commons.wikimedia.org/wiki/File:Shallow_water_wave.gif.

When does a wave break? Do waves only break when they reach shore? Waves break when they become too tall to

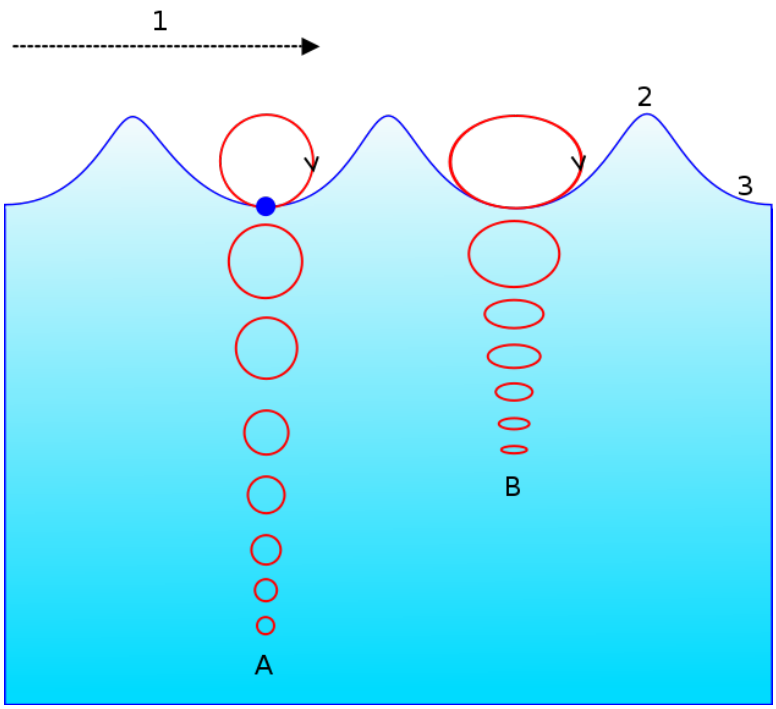


FIGURE 1.9

The circles show the motion of a water molecule in a wind wave. Wave energy is greatest at the surface and decreases with depth. A shows that a water molecule travels in a circular motion in deep water. B shows that molecules in shallow water travel in an elliptical path because of the ocean bottom.

be supported by their base. This can happen at sea but happens predictably as a wave moves up a shore. The energy at the bottom of the wave is lost by friction with the ground so that the bottom of the wave slows down but the top of the wave continues at the same speed. The crest falls over and crashes down.

Some of the damage done by storms is from **storm surge**. Water piles up at a shoreline as storm winds push waves into the coast. Storm surge may raise sea level as much as 7.5 m (25 ft), which can be devastating in a shallow land area when winds, waves, and rain are intense.

A wild video of "Storm Surge" can be seen on National Geographic Videos, Environment Video, Natural Disasters, Landslides, and more: : http://video.nationalgeographic.com/video/player/environment/

=KQED: Science of Big Waves

Maverick waves are massive. Learning how they are generated can tell scientists a great deal about how the ocean creates waves and especially large waves. Learn more at:http://www.kqed.org/quest/television/science-of-big-waves

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Tsunami

Tsunami are described in the Earthquakes chapter as damaging waves that result from the sharp jolt to the water from an undersea earthquake. Landslides, meteorite impacts, or any other jolt to ocean water may form a tsunami (**Figure** 1.10). Tsunami can travel at speeds of 800 kilometers per hour (500 miles per hour).

Tsunami have small wave heights and long wavelengths so they are usually unnoticed at sea. As the wave rides up the continental shelf the wave height increases.

A video explanation of tsunami is here: http://www.youtube.com/watch?v=StdqGoezNrY&feature=channel

The wave speed of a tsunami is also slowed by friction with the shallower ocean floor, which causes the wavelength to decrease, creating a much taller wave.

Many people caught in a tsunami have no warning of its approach. Since the wavelength is long, a long time can pass between crests or troughs onshore. In 1755 in Lisbon, an offshore earthquake caused a great deal of damage on land. People rushed to the open space of the shore and discovered that the water was flowing seaward fast. The trough of the tsunami wave reached shore first. People who went out onto the open beach were drowned when the crest of the wave reached shore.

FIGURE 1.10
A wave from the 2004 Boxing Day Tsunami hits the Maldives in the Indian Ocean.

KQED: Science on the SPOT: Watching the Tides

Large tsunami in the Indian Ocean and more recently Japan have killed hundreds of thousands of people in recent years. The west coast is vulnerable to tsunami since it sits on the Pacific Ring of Fire. Scientists are trying to learn everything they can about predicting tsunamis before a massive one strikes a little closer to home. Learn more at: http://science.kqed.org/quest/video/scary-tsunamis/

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Tides

Tides are the daily rise and fall of sea level at any given place. The pull of the Moon's gravity on Earth is the primarily cause of tides and the pull of the Sun's gravity on Earth is the secondary cause (**Figure** 1.11). The Moon has a greater effect because, although it is much smaller than the Sun, it is much closer. The Moon's pull is about twice that of the Sun's.

FIGURE 1.11
High tide (left) and low tide (right) at Bay of Fundy on the Gulf of Maine. The Bay of Fundy has the greatest tidal ranges on Earth at 38.4 feet.

Daily Tide Patterns

To understand the tides it is easiest to start with the effect of the Moon on Earth. As the Moon revolves around our planet, its gravity pulls Earth toward it. The lithosphere is unable to move much but the water is pulled by the gravity and a bulge is created. This bulge is the high tide beneath the Moon. Centrifugal forces create an equal high tide bulge on the opposite side of Earth from the Moon. These two water bulges on opposite sides of the Earth aligned with the Moon are the **high tides**.

Since so much water is pulled into the two high tides, **low tides** form between the two high tides (**Figure** 1.12). As the Earth rotates beneath the Moon, a single spot will experience two high tides and two low tides every day.

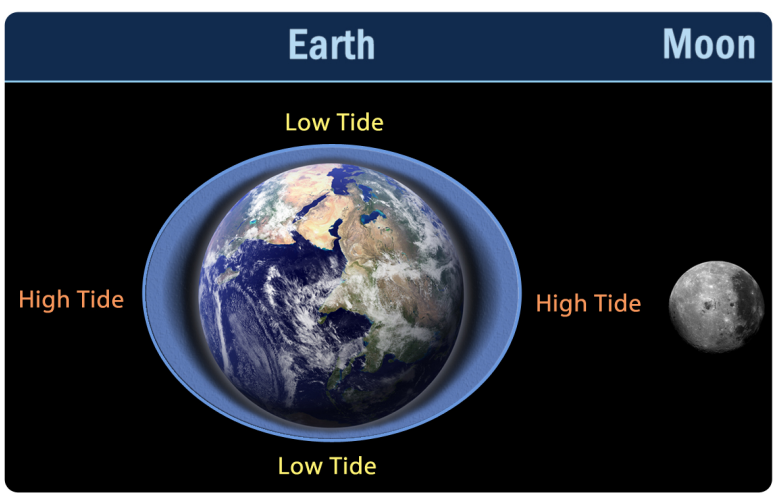

FIGURE 1.12
The gravitational attraction of the Moon to ocean water creates the high and low tides.

A detailed animation of lunar tides is shown here: http://www.pbs.org/wgbh/nova/venice/tides.html

The **tidal range** is the difference between the ocean level at high tide and the ocean at low tide (**Figure** 1.13). The

tidal range in a location depends on a number of factors, including the slope of the seafloor. Water appears to move a greater distance on a gentle slope than on a steep slope.

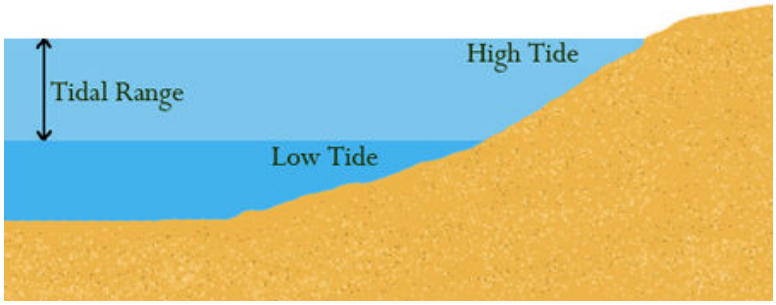

FIGURE 1.13
The tidal range is the difference between the ocean level at high tide and low tide.

Monthly Tide Patterns

If you look at the diagram of high and low tides on a circular Earth above, you'll see that tides are waves. So when the Sun and Moon are aligned, what do you expect the tides to look like?

Waves are additive so when the gravitational pull of both bodies is in the same direction the high tides add and the low tides add (**Figure** 1.14). Highs are higher and lows are lower than at other times through the month. These more extreme tides, with a greater tidal range, are called **spring tides**. Spring tides don't just occur in the spring; they occur whenever the Moon is in a new-moon or full-moon phase, about every 14 days.

Here is a link to see these tides in motion: http://oceanservice.noaa.gov/education/kits/tides/media/tide06a_450.gif.

Neap tides are tides that have the smallest tidal range, and they occur when the Earth, the Moon, and the Sun form a 90° angle (**Figure** 1.15). They occur exactly halfway between the spring tides, when the Moon is at first or last quarter. How do the tides add up to create neap tides? The Moon's high tide occurs in the same place as the Sun's low tide and the Moon's low tide in the same place as the Sun's high tide. At neap tides, the tidal range relatively small.

A simple animation of spring and neap tides is found here: http://oceanservice.noaa.gov/education/kits/tides/media/supp_tide06a.html.

High tides occur about twice a day, about every 12 hours and 25 minutes. The reason is that the Moon takes 24 hours and 50 minutes to rotate once around the Earth so the Moon is over the same location 24 hours and 50 minutes later. Since high tides occur twice a day, one arrives each 12 hours and 25 minutes. What is the time between a high tide and the next low tide?

This animation shows the effect of the Moon and Sun on the tides: http://www.onr.navy.mil/focus/ocean/motion/tides1.htm.

Some coastal areas do not follow this pattern at all. These coastal areas may have one high and one low tide per day or a different amount of time between two high tides. These differences are often because of local conditions, such as the shape of the coastline that the tide is entering.

Surface Currents

Ocean water moves in predictable ways along the ocean surface. **Surface currents** can flow for thousands of kilometers and can reach depths of hundreds of meters. These surface currents do not depend on weather; they remain unchanged even in large storms because they depend on factors that do not change.

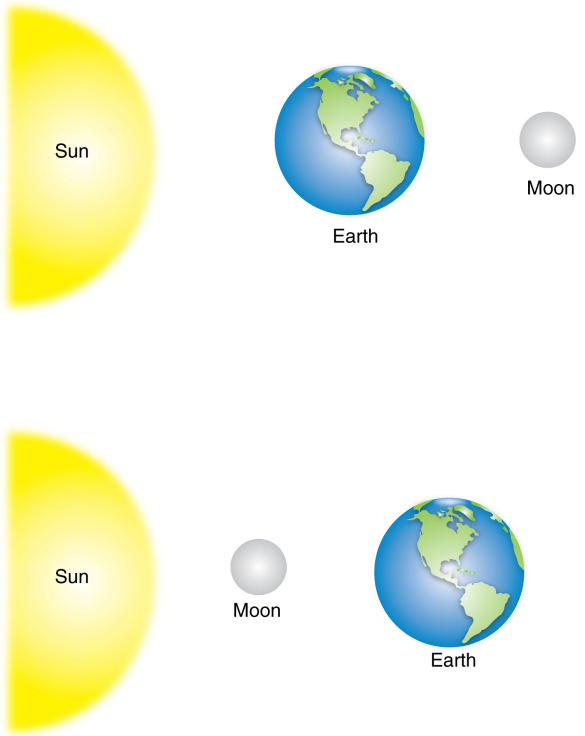

FIGURE 1.14
Spring tides occur the tidal bulges from the Moon and Sun are aligned. The Moon is full in this image; in the bottom image the Moon would appear as a new Moon

Surface currents are created by three things:

- global wind patterns
- the rotation of the Earth
- the shape of the ocean basins

Surface currents are extremely important because they distribute heat around the planet and are a major factor influencing climate around the globe.

Global Wind Patterns

Winds on Earth are either global or local. Global winds blow in the same directions all the time and are related to the unequal heating of Earth by the Sun – that is, more solar radiation strikes the equator than the polar regions — and the rotation of the Earth – that is, the **Coriolis effect**. The causes of the global wind patterns will be described in detail in the Earth's Atmosphere chapter.

Water in the surface currents is pushed in the direction of the major wind belts:

- trade winds: east to west between the equator and 30^oN and 30^oS
- westerlies: west to east in the middle latitudes
- polar easterlies: east to west between 50° and 60° north and south of the equator and the north and south pole

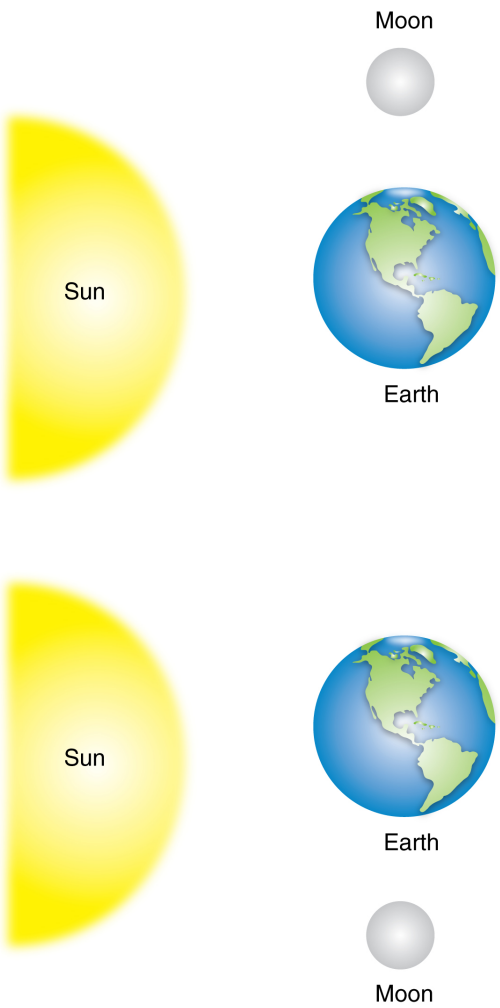

FIGURE 1.15
Neap tides occur when the Earth, the Sun, and the Moon form a right angle; the Moon is in its first or third quarter.

Earth's Rotation

Wind is not the only factor that affects ocean currents. The Coriolis effect describes how Earth's rotation steers winds and surface ocean currents (**Figure** 1.16). Coriolis causes freely moving objects to appear to move to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. The objects themselves are actually moving straight, but the Earth is rotating beneath them, so they seem to bend or curve.

An example might make the Coriolis effect easier to visualize. If an airplane flies 500 miles due north, it will not arrive at the city that was due north of it when it began its journey. Over the time it takes for the airplane to fly 500 miles, that city moved, along with the Earth it sits on. The airplane will therefore arrive at a city to the west of the original city (in the Northern Hemisphere), unless the pilot has compensated for the change. So to reach his intended destination, the pilot must also veer right while flying north.

As wind or an ocean current moves, the Earth spins underneath it. As a result, an object moving north or south along the Earth will appear to move in a curve, instead of in a straight line. Wind or water that travels toward the poles from the equator is deflected to the east, while wind or water that travels toward the equator from the poles gets bent to the west. The Coriolis effect bends the direction of surface currents to the right in the Northern Hemisphere and left in the Southern Hemisphere.

FIGURE 1.16

The Coriolis effect causes winds and currents to form circular patterns. The direction that they spin depends on the hemisphere that they are in.

Coriolis effect is demonstrated using a metal ball and a rotating plate in this video. The ball moves in a circular path just like a freely moving particle of gas or liquid moves on the rotating Earth **(5b)**: http://www.youtube.com/watch?v=Wda7azMvabE&feature=related (2:04).

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Shape of the Ocean Basins

When a surface current collides with land, the current must change direction (**Figure** 1.17). In the figure below, the Atlantic South Equatorial Current travels westward along the equator until it reaches South America. At Brazil, some of it goes north and some goes south. Because of Coriolis effect, the water goes right in the Northern Hemisphere and left in the Southern Hemisphere.

You can see on the map of the major surface ocean currents that the surface ocean currents create loops called **gyres** (**Figure** 1.18). The Antarctic Circumpolar Current is unique because it travels uninhibited around the globe. Why is

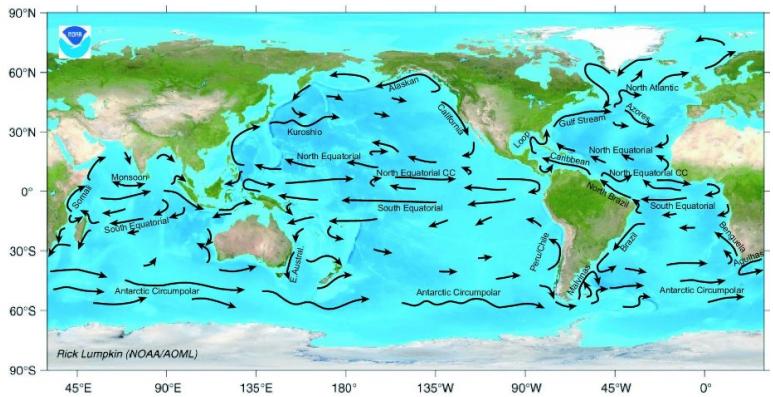

FIGURE 1.17
The major surface ocean currents.

it the only current to go all the way around?

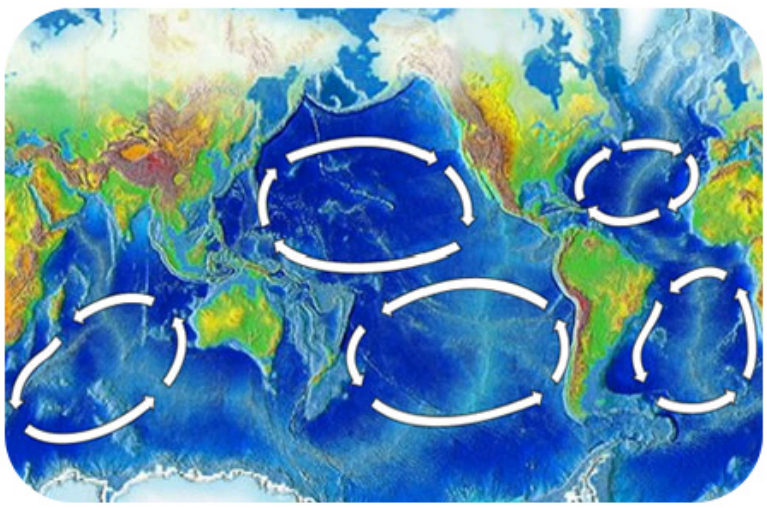

FIGURE 1.18
The ocean gyres. Why do the Northern Hemisphere gyres rotate clockwise and the Southern Hemisphere gyres rotate counterclockwise?

This video shows the surface ocean currents set by global wind belts **(5a)**: http://www.youtube.com/watch?v=Hu_Ga0JYFNg (1:20).

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Local Surface Currents

The surface currents described above are all large and unchanging. Local surface currents are also found along shorelines (**Figure** 1.19). Two are **longshore currents** and **rip currents**.

Rip currents are potentially dangerous currents that carry large amounts of water offshore quickly. Look at the

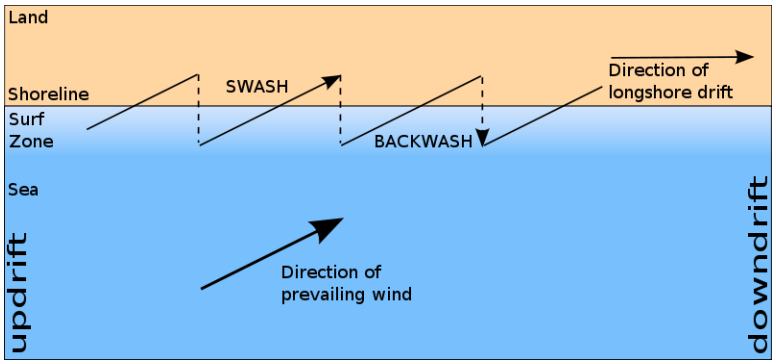


FIGURE 1.19
Longshore currents move water and sediment parallel to the shore in the direction of the prevailing local winds.

rip-current animation to determine what to do if you are caught in a rip current: http://www.onr.navy.mil/focus/ocean/motion/currents2.htm. Each summer in the United States at least a few people die when they are caught in rip currents.

This animation shows the surface currents in the Caribbean, the Gulf of Mexico, and the Atlantic Ocean off of the southeastern United States: http://polar.ncep.noaa.gov/ofs/viewer.shtml?-gulfmex-cur-0-large-rundate=latest.

Effect on Global Climate

Surface currents play an enormous role in Earth's climate. Even though the equator and poles have very different climates, these regions would have more extremely different climates if ocean currents did not transfer heat from the equatorial regions to the higher latitudes.

The Gulf Stream is a river of warm water in the Atlantic Ocean, about 160 kilometers wide and about a kilometer deep. Water that enters the Gulf Stream is heated as it travels along the equator. The warm water then flows up the east coast of North America and across the Atlantic Ocean to Europe (**Figure** 1.20). The energy the Gulf Stream transfers is enormous: more than 100 times the world's energy demand.

The Gulf Stream's warm waters raise temperatures in the North Sea, which raises the air temperatures over land between 3 to 6°C (5 to 11°F). London, U.K., for example, is at the same latitude as Quebec, Canada. However, London's average January temperature is 3.8^{o}C (38°F), while Quebec's is only -12°C (10°F). Because air traveling over the warm water in the Gulf Stream picks up a lot of water, London gets a lot of rain. In contrast, Quebec is much drier and receives its precipitation as snow.

Deep Currents

Thermohaline circulation drives deep ocean circulation. Thermo means heat and haline refers to salinity. Differences in temperature and in salinity change the density of seawater. So thermohaline circulation is the result of density differences in water masses because of their different temperature and salinity.

What is the temperature and salinity of very dense water? Lower temperature and higher salinity yield the densest water. When a volume of water is cooled, the molecules move less vigorously so same number of molecules takes up less space and the water is denser. If salt is added to a volume of water, there are more molecules in the same volume so the water is denser.

Changes in temperature and salinity of seawater take place at the surface. Water becomes dense near the poles. Cold polar air cools the water and lowers its temperature, increasing its salinity. Fresh water freezes out of seawater to become sea ice, which also increases the salinity of the remaining water. This very cold, very saline water is very dense and sinks. This sinking is called **downwelling**.

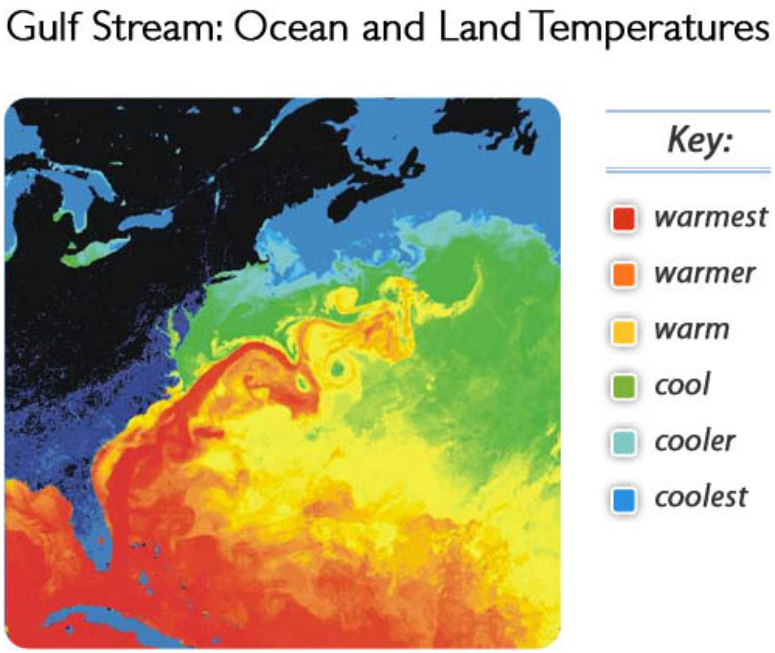
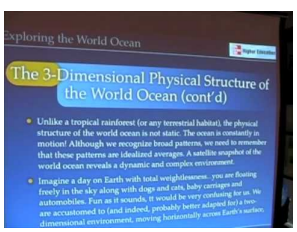


FIGURE 1.20

In a satellite image of water temperature in the western Atlantic it is easy to pick out the Gulf Stream, which brings warmer waters from the equator up eastern North America.

This video lecture discusses the vertical distribution of life in the oceans. Seawater density creates currents, which provide different habitats for different creatures **(5d)**: http://www.youtube.com/watch?v=LA1jxeXDsdA (6:12).



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Two things then happen. The dense water pushes deeper water out of its way and that water moves along the bottom of the ocean. This deep water mixes with less dense water as it flows. Surface currents move water into the space vacated at the surface where the dense water sank (**Figure** 1.21). Water also sinks into the deep ocean off of Antarctica.

Since unlimited amounts of water cannot sink to the bottom of the ocean, water must rise from the deep ocean to the surface somewhere. This process is called **upwelling** (**Figure** 1.22).

Generally, upwelling occurs along the coast when wind blows water strongly away from the shore. This leaves a void that is filled by deep water that rises to the surface.

Upwelling is extremely important where it occurs. During its time on the bottom, the cold deep water has collected nutrients that have fallen down through the water column. Upwelling brings those nutrients to the surface. Those nutrient support the growth of plankton and form the base of a rich ecosystem. California, South America, South Africa, and the Arabian Sea all benefit from offshore upwelling.

An animation of upwelling is seen here: http://oceanservice.noaa.gov/education/kits/currents/03coastal4.html.

Upwelling also takes place along the equator between the North and South Equatorial Currents. Winds blow the surface water north and south of the equator so deep water undergoes upwelling. The nutrients rise to the surface and support a great deal of life in the equatorial oceans.

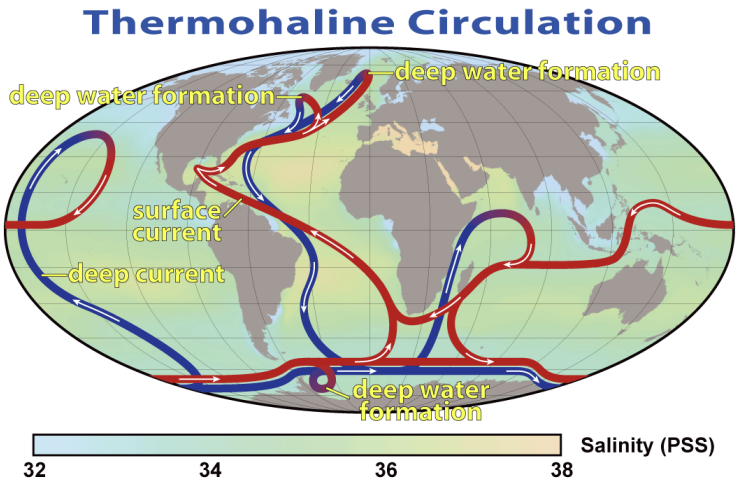

FIGURE 1.21

Cold water (blue lines) sinks in the North Atlantic, flows along the bottom of the ocean and upwells in the Pacific or Indian. The water then travels in surface currents (red lines) back to the North Atlantic. Deep water also forms off of Antarctica.

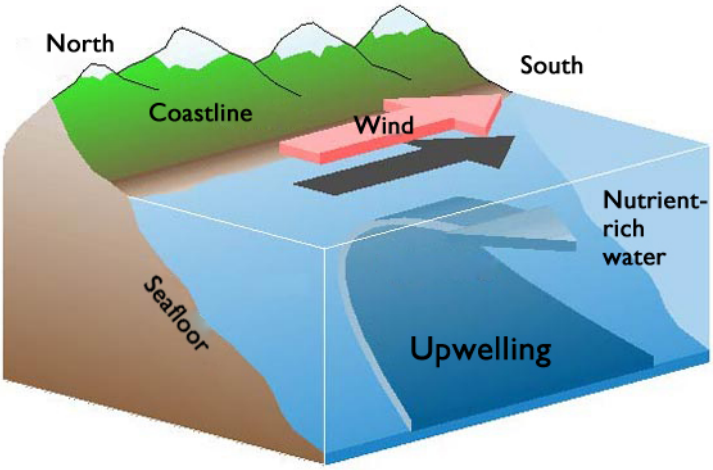

FIGURE 1.22

Upwelling forces denser water from below to take the place of less dense water at the surface that is pushed away by the wind.

Lesson Summary

- Ocean waves are energy traveling through the water.
- Most ocean waves are generated by wind. Tsunami are exceptionally long wavelength waves usually caused by earthquakes.
- Tides are produced by the gravitational pull of the Moon and Sun.
- Spring tides have large tidal ranges and occur at full and new moons, when Earth, Moon, and Sun are all aligned.
- Neap tides have low tidal ranges and occur at first and last quarter moons, when the Moon is at right angles to the Sun.
- Ocean surface currents are produced by global winds, the Coriolis effect and the shape of each ocean basin.
- The Pacific and Atlantic Oceans have a circular pattern of surface currents called gyres that circle clockwise in the Northern Hemisphere and counterclockwise in the Southern. The Indian Ocean only has a counterclockwise gyre.
- Surface ocean circulation brings warm equatorial waters towards the poles and cooler polar water towards the equator.

- Thermohaline circulation drives deep ocean currents.
- Upwelling of cold, nutrient-rich waters creates biologically rich areas where surface waters are blown away from a shore, or where equatorial waters are blow outward.

Review Questions

1. What factors of wind determine the size of a wave?
2. Tsunami are sometimes incorrectly called "tidal waves." Explain why this is not correct.
3. Describe what causes the tides.
4. What is a tidal range? In what types of tides is the tidal range greatest? Lowest?
5. Why do some places have a greater tidal range than other places?
6. What causes the patterns of surface currents in the ocean?
7. How do ocean surface currents affect climate?
8. What is the Coriolis effect?
9. What process can make deep, dense water rise to the surface?
10. Why are upwelling areas important to marine life?

Further Reading / Supplemental Links

- Learn About Ocean Currents, 5 min. Life Videopedia http://www.5min.com/Video/Learn-about-Ocean-Currents-117529352
- NOAA's Ocean Explorer program http://oceanexplorer.noaa.gov/edu/welcome.html
- A tutorial for grades 6 to 12 on currents from NOAA: http://oceanservice.noaa.gov/education/tutorial_currents/welcome.html
- Cool jobs: Oceanographer http://news.discovery.com/videos/cool-jobs-cool-jobs-oceanographer.html

Points to Consider

- Some scientists have hypothesized that if enough ice in Greenland melts, the Gulf Stream might be shut down. Why might this happen?
- If the Gulf Stream shuts down, what would be the result on climate in Europe?
- How do the movements of ocean water contribute to the ocean's life?

Going Further - Applying Math

Tide Generating Force

In this exercise you will use an equation to calculate the tide generating force. Like the force of gravity, the pull of the tide generating force is directly related to the masses of the astronomical objects involved and inversely related to the square of the distance between them. Tides are caused by both the gravitational pull of the Moon and the gravitational pull of the Sun on surface water. Unlike the gravitational force, the tide generating force varies with the distance between the Moon (or the Sun) and the Earth cubed.

The equation for the tide generating force is: T = G (m1 . m2 / d3) where T is the tide generating force, G is the universal gravitational constant, m1 and m2 are the mass of the Earth and the mass of the Moon (or the mass of the Earth and the mass of the Sun), and d is the distance between them.

If we plug in values for the gravitational constant, the mass of the Earth and the mass of the Moon, we can calculate the tide generating force when the Moon is at apogee (farthest from the Earth in its orbit). Use G = 6.673 x 10 -11 m 3 / kg . s 2; m 1 = 7.35 x 10 22 kg for the mass of the Moon, m 2 = 5.974 x 10 24 kg for the mass of the Earth; and d = 405,500 km for the distance from the Earth to the Moon at apogee.

You could use all the same values but substitute in d = 363,300 km for the distance from the Earth to the Moon when the Moon is at perigee (point when the Moon is closest to the Earth) and compare the tide generating force each distance.

Tsunami Tag

Could you outrun a tsunami? How fast would you have to run? You can calculate how fast a tsunami travels in the ocean using the equation for the speed of a shallow water wave, which is: V = the square root of g x d, where V = wave speed (velocity), g = the acceleration of gravity: 9.8 meters / s 2, and d = the depth of the water. If you use d = 3,940m (the average depth of the Pacific Ocean), how fast does a tsunami travel? Do you think you could outrun this wave?

1.3 The Seafloor

Lesson Objectives

- Describe the methods scientists have for studying the seafloor.
- Describe the features of the seafloor.
- List the living and non-living resources that people use from the seafloor.

Vocabulary

- bottom trawling
- manganese nodule

Introduction

Oceanographers like to say that we know more about the dark side of the Moon than we do about the oceans. That statement is doubly true of the seafloor. Although modern technology has allowed us to learn more about the seafloor, vast regions remain unexplored.

Studying the Seafloor

Scuba divers can only dive to about 40 meters and they cannot stay down there for very long. Although this is good for researching the organisms and ecosystems very near a coast, most oceanic research requires accessing greater depths.

Mapping

In the Plate Tectonics chapter you learned that echo sounders designed to locate enemy submarines allowed scientists to create bathymetric maps of the seafloor (**Figure** 1.23). Prior to this advance, explorers mapped a small amount of the seafloor by painstakingly dropping a line over the side of a ship to measure the depth at one tiny spot at a time.

KQED: Sea 3-D: Charting the Ocean Floor

Using sound and laser technology, researchers have begun to reveal the secrets of the ocean floor from the Sonoma Coast to Monterey Bay. By creating complex 3-D maps, they're hoping to learn more about waves and achieve ambitious conservation goals. Learn more at:http://science.kqed.org/quest/video/sea-3-d-charting-the-ocean-floor/

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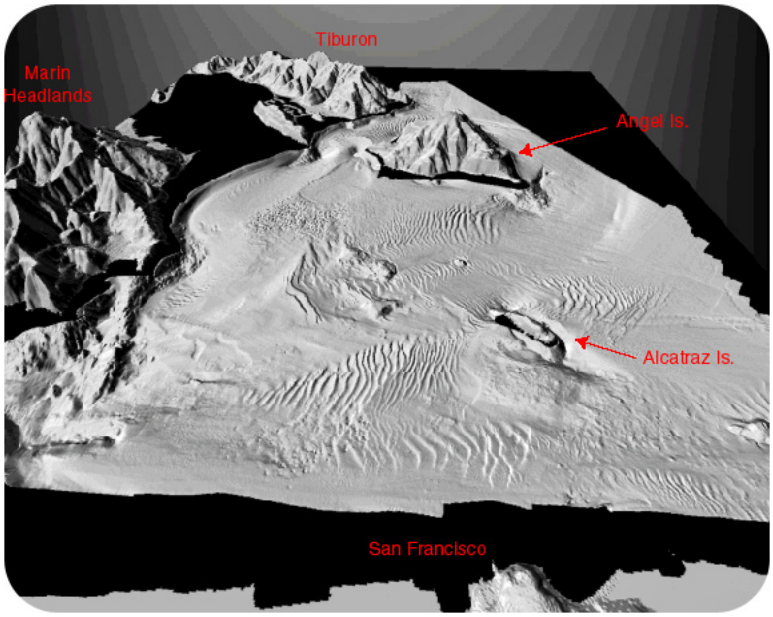

FIGURE 1.23
Map of San Francisco Bay, oblique view.

Sampling Remotely

Samples of seawater from different depths in the water column are needed to understand ocean chemistry. To do this bottles are placed along a cable at regular depths and closed as a weight is dropped down the cable. The water trapped in the bottle can be analyzed later in a laboratory (**Figure** 1.24).

Scientists are also interested in collecting rock and sediment samples from the seafloor. A dredge is a giant rectangular bucket that is dragged along behind a ship to collect loose rocks. Gravity corers are metal tubes that fall to the seafloor and slice into the sediments to collect a sample. The research vessel, the Joides Resolution, drills deep into the seafloor to collect samples of the sediment and ocean crust. Scientists analyze the samples for chemistry and paleomagnetism.

Videos of the drill bit and core samples taken by the Joides Resolution are seen here: http://www.youtube.com/watch?v=4c9HlHBCSCY&feature=channel; http://www.youtube.com/watch?v=MXqlRUbqHz0&feature=channel; http://www.youtube.com/watch?v=50VeS0TxCvU&feature=channel.

Submersibles

Samples of seawater and rocks can be collected directly by scientists in a submersible. These subs can take scientists down to make observations and the subs have arms for collecting samples. The submersible Alvin is an HOV, a human operated vehicle. Alvin can dive up to 4,500 m beneath the ocean surface and has made more than 4000 dives since 1964 (**Figure** 1.25).

View a slide show of DSV Alvin and its history from the Woods Hole Oceanographic Institution: http://www.whoi.edu/page.do?pid=8422&tid=201&cid=14616&ct=362#.

Remotely Operated Vehicles

To avoid the expense, dangers, and limitations of human missions under the sea, remotely operated vehicles or ROV's, allow scientists to study the ocean's depths by using small vehicles carrying cameras and scientific instruments. ROVs were used to study the Titanic, which would have been far too dangerous for a manned sub to enter.

FIGURE 1.24
A Niskin bottle being deployed off the side of a research ship.

Scientists control ROVs electronically with sophisticated operating systems (**Figure** 1.26).

Footage of the NOAA Titanic Expedition of 2004 is visible in this video: http://www.youtube.com/watch?v=6Z7REEnwKOQ.

A video of the ROV Nereus from the Woods Hole Oceanographic Institution is shown here: http://www.youtube.com/watch?v=wwdF_2wMRfU&feature=channel.

Ocean Resources

The ocean provides important living and non-living resources. To be maintained for future use, these resources must be managed sustainably.

Living Resources

Most fish are caught by lines or nets as they swim in the open waters of the ocean. Some species of fish are being overharvested, which means their rate of reproduction cannot keep up with the rate at which people consume them.

Bottom trawling is a method of fishing that involves towing a weighted net across the seafloor to harvest fish. In many areas where bottom trawling is done, ecosystems are severely disturbed by the large nets. For this reason, in a few areas in the world, laws limit bottom trawling to waters not more than 1,000 m deep or waters far from protected and sensitive areas. Still these actions protect some of the seafloor. Besides food, ocean organisms have other uses. Some provide us with medications.

FIGURE 1.25
Alvin allows two people and a pilot to make a nine hour dive.

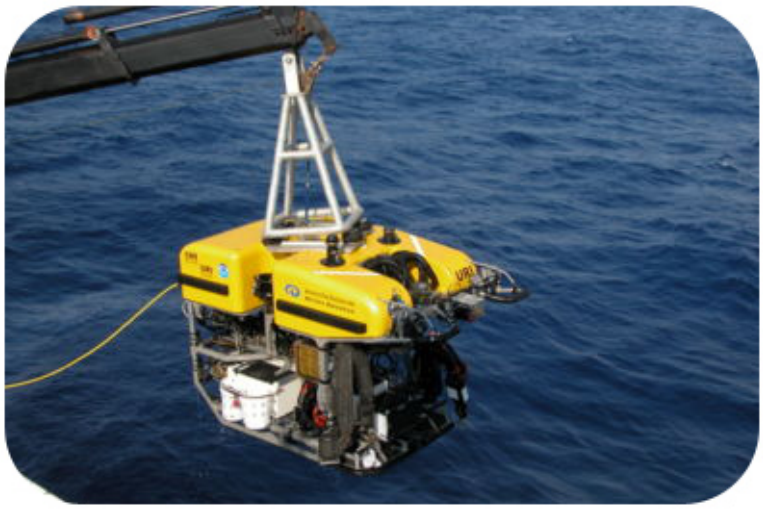

FIGURE 1.26
Remotely operated vehicles such as this one allow scientists to study the seafloor.

Non-living Resources

Oil and natural gas are the most valuable non-living resources taken from the ocean. Extracting these resources requires drilling into the seafloor. Oil platforms have dozens of oil wells that are drilled in places where the ocean is sometimes 2,000 m deep (**Figure** 1.27). A description of the Deepwater Horizon oil spill affecting the Gulf of Mexico is located in the Human Actions and Earth's Waters chapter.

FIGURE 1.27
Oil platforms can be fixed or they can float.

The seafloor has some valuable minerals. **Manganese nodules** containing manganese, iron, copper, nickel, phosphate, and cobalt (**Figure** 1.28) may be as small as a pea or as large as a basketball. Estimates are that there may be as much as 500 billion tons of nodules on the seafloor. The minerals in manganese nodules have many uses in the industrial world, but currently they are not being mined. Think back to the discussion of ore deposits in the Earth's Minerals chapter. Why do you think these seafloor resources are not being mined?

Lesson Summary

- Scuba divers can only explore near the surface so most oceanographic research is done from satellites, ships, and submersibles.
- The oceans are divided into zones by water depth, distance from shore, and the slope of the seafloor.
- The oceans provide us with both living and non-living resources.

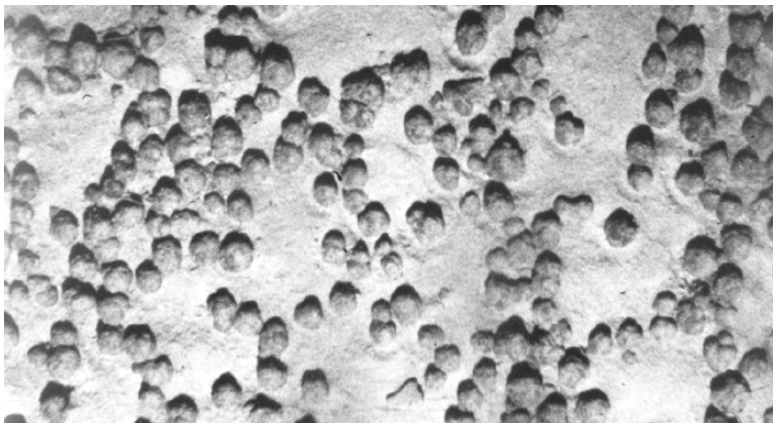

FIGURE 1.28
Manganese nodules from the seafloor are often rich in metals such as manganese, iron, nickel, copper, and cobalt.

- Living oceanic resources include fish and invertebrates used for food.
- The most valuable non-living resources from the oceans are oil and natural gas.

Review Questions

1. Scientists sometimes say that we know less about the oceans than the far side of the Moon. Why is it so difficult to learn about the oceans?

2. The atmospheric pressure is about 1 kilogram per centimeter squared (14.7 pounds per square inch or 1 atmosphere) at sea level. About what is the pressure if you are 100 meters deep in the ocean?

3. Where on the ocean floor will you find the greatest amount of living organisms?

4. Compare and contrast the continental shelf and the abyssal plain.

5. Why do you think mapping the seafloor is important to the Navy? What part of the seafloor is the navy most interested in?

6. Why is bottom trawling damaging to the seafloor?

7. As world population grows and the ocean is called on to provide more and more resources, what can people do to be sure the resources are used sustainably?

8. What is a manganese nodule?

Further Reading / Supplemental Links

News and information about the ROV Alvin: http://www.whoi.edu/page.do?pid=8422

More about the Joides Resolution: http://joidesresolution.org/

Points to Consider

- If the seafloor is not well known, how much do you think is known about marine life?
- What methods are needed to learn about organisms at the ocean surface, the mid-depths, or on the seafloor?
- Are techniques that are used for understanding ocean physics, chemistry, and geology also useful for studying marine life?

1.4 Ocean Life

Lesson Objectives

- Describe the different types of ocean organisms.
- Describe the interactions among different ocean organisms.

Vocabulary

- chemosynthesis
- hydrothermal vent
- invertebrate
- phytoplankton
- plankton
- primary productivity
- reef
- vertebrate
- zooplankton

Introduction

Oceans are a harsh placed to live. In the intertidal zone, conditions change rapidly as water covers and uncovers the region and waves pound on the rocks. Most of the environments at sea are cold and at just about any depth below the surface the pressure is very high. Beyond the photic zone, the ocean is entirely black. Organisms have adapted to these conditions in many interesting and effective ways. The size and variety of different habitats means that the oceans are home to a large portion of all life on Earth.

Types of Ocean Organisms

The smallest and largest animals on Earth live in the oceans. Why do you think the oceans can support large animals?

Marine animals breathe air or extract oxygen from the water. Some float on the surface and others dive into the ocean's depths. There are animals that eat other animals, and plants generate food from sunlight. A few bizarre creatures break down chemicals to make food! The following section divides ocean life into seven basic groups.

Plankton

Plankton are organisms that cannot swim but that float along with the current. The word "plankton" comes from the Greek for wanderer. Most plankton are microscopic, but some are visible to the naked eye (**Figure** 1.29).

Phytoplankton are tiny plants that make food by photosynthesis. Because they need sunlight, phytoplankton live in the photic zone. Phytoplankton are responsible for about half of the total **primary productivity** (food energy) on Earth. Like other plants, phytoplankton release oxygen as a waste product.

A video of a research vessel sampling plankton is seen here: http://www.youtube.com/watch?v=mQG4zAoh6xc&feature=channel.

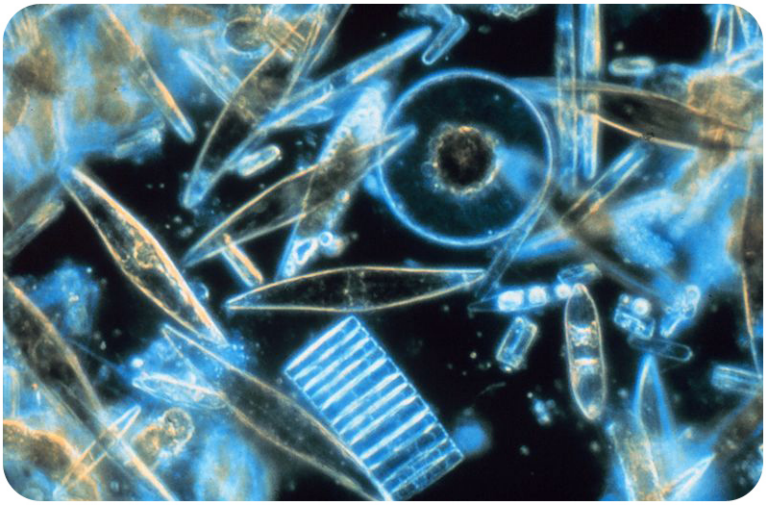

FIGURE 1.29
Microscopic diatoms are a type of phytoplankton.

Zooplankton, or animal plankton, eat phytoplankton as their source of food (**Figure** 1.30). Some zooplankton live as plankton all their lives and others are juvenile forms of animals that will attach to the bottom as adults. Some small invertebrates live as zooplankton.

FIGURE 1.30
Copepods are abundant and so are an important food source for larger animals.

Plants and Algae

The few true plants found in the oceans include salt marsh grasses and mangrove trees. Although they are not true plants, large algae, which are called seaweed, also use photosynthesis to make food. Plants and seaweeds are found in the neritic zone where the light they need penetrates so that they can photosynthesize (**Figure** 1.31).

FIGURE 1.31
Kelp grow in forests in the neritic zone. Otters and other organisms depend on the kelp-forest ecosystem.

Marine Invertebrates

The variety and number of **invertebrates**, animals without a backbone, is truly remarkable (**Figure** 1.32). Marine invertebrates include sea slugs, sea anemones, starfish, octopi, clams, sponges, sea worms, crabs, and lobsters. Most of these animals are found close to the shore, but they can be found throughout the ocean.

KQED: Amazing Jellies

Jellies are otherworldly creatures that glow in the dark, without brains or bones, some more than 100 feet long. Along with many other ocean areas, they live just off California's coast. Learn more at:http://science.kqed.org/quest/video/amazing-jellies/

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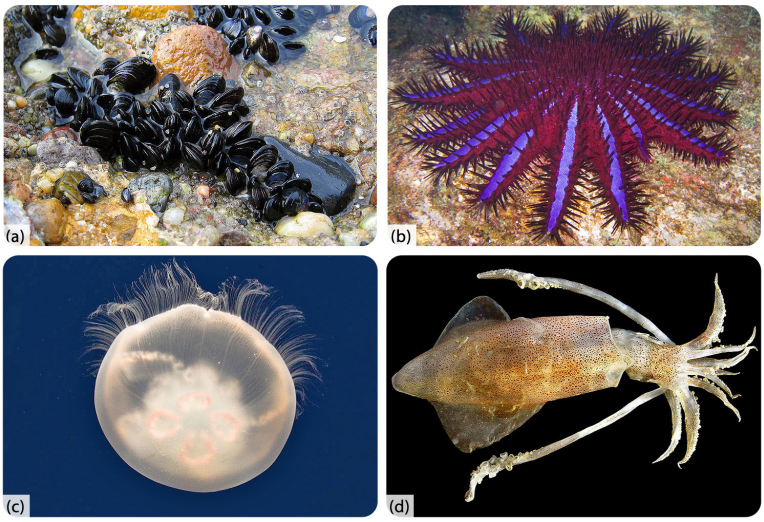

FIGURE 1.32
(a) Mussels; (b) Crown of thorns sea star; (c) Moon jelly; (d) A squid.

Fish

Fish are **vertebrates**; they have a backbone. What are some of the features fish have that allows them to live in the oceans? All fish have most or all of these traits.

- Fins with which to move and steer.
- Scales for protection.
- Gills for extracting oxygen from the water.
- A swim bladder that lets them rise and sink to different depths.
- Ectothermy (cold-bloodedness) so that their bodies are the same temperature as the surrounding water.
- Bioluminescence: light created from a chemical reaction that can attract prey or mates in the dark ocean.

Included among the fish are sardines, salmon, and eels, as well as the sharks and rays (which lack swim bladders) (**Figure** 1.33).

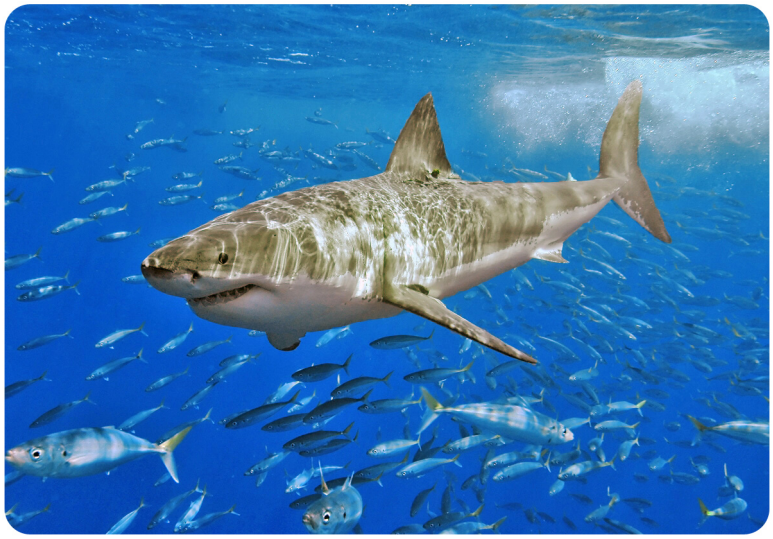

FIGURE 1.33
The Great White Shark is a fish that preys on other fish and marine mammals.

Reptiles

Only a few types of reptiles live in the oceans and they live in warm water. Why are reptiles so restricted in their ability to live in the sea? Sea turtles, sea snakes, saltwater crocodiles, and marine iguana that are found only at the Galapagos Islands sum up the marine reptile groups (**Figure** 1.34). Sea snakes bear live young in the ocean, but turtles, crocodiles, and marine iguanas all lay their eggs on land.

FIGURE 1.34
Sea turtles are found all over the oceans, but their numbers are diminishing.

Seabirds

Many types of birds are adapted to living in the sea or on the shore. A few are shown: (**Figure** 1.35).

Marine Mammals

What are the common traits of mammals? Mammals are endothermic (warm-blooded) vertebrates that give birth to live young; feed them with milk; and have hair, ears, and a jaw bone with teeth.

What traits might mammals have to be adapted to life in the ocean?

- For swimming: streamlined bodies, slippery skin or hair, fins.
- For warmth: Fur, fat, high metabolic rate, small surface area to volume, specialized blood system.
- For salinity: kidneys that excrete salt, impervious skin.

The five types of marine mammals are pictured here: (**Figure** 1.36).

KQED: Into the Deep with Elephant Seals

Thousands of northern elephant seals — some weighing up to 4,500 pounds — make an annual migration to breed each winter at Año Nuevo State Reserve in California. Marine biologists are using high-tech tools to explore the

FIGURE 1.35

(a) With their long legs for wading and long bills for digging in sand for food, shorebirds are well adapted for the intertidal. (b) Many seabirds live on land but go to sea to fish, such as gulls, pelicans, and this frigate bird. (c) Albatross spend months at sea and only come on shore to raise chicks.

FIGURE 1.36

(a) Cetaceans: whales, dolphins, and porpoises. (b) Sirenians: manatee and the dugong. (c) Mustelids: Sea otters (terrestrial members are skunks, badgers and weasels). (d) Pinnipeds: Seals, sea lions, and walruses. (e) Polar bear.

secrets of these amazing creatures. Learn more at: http://science.kqed.org/quest/video/into-the-deep-with-elephant-seals/

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Interactions Among Ocean Organisms

The previous section briefly discussed the adaptations different types of organisms have to live in the ocean. A look at a few of the different habitats organisms live in can focus even more on these important adaptations.

The Intertidal

A great abundance of life is found in the intertidal zone (**Figure** 1.37). High energy waves pound the organisms that live in this zone and so they must be adapted to pounding waves and exposure to air during low tides. Hard shells protect from pounding waves and also protect against drying out when the animal is above water. Strong attachments keep the animals anchored to the rock.

FIGURE 1.37

This tide pool shows a zonation in the types of organism.

In a tide pool, as in the photo, what organisms are found where and what specific adaptations do they have to that zone? The mussels on the top left have hard shells for protection and to prevent drying because they are often not covered by water. The sea anemones in the lower right are more often submerged and have strong attachments but can close during low tides.

Many young organisms get their start in estuaries and so they must be adapted to rapid shifts in salinity.

Reefs

Corals and other animals deposit calcium carbonate to create rock **reefs** near the shore. Coral reefs are the "rainforests of the oceans" with a tremendous amount of species diversity (**Figure** 1.38).

Reefs can form interesting shapes in the oceans. Remember that hot spots create volcanoes on the seafloor. If these volcanoes rise above sea level to become islands, and if they occur in tropical waters, coral reefs will form on them. Since the volcanoes are cones, the reef forms in a circle around the volcano. As the volcano comes off the hot spot, the crust cools. The volcano subsides and then begins to erode away (**Figure** 1.39).

Eventually, all that is left is a reef island called an atoll. A lagoon is found inside the reef (**Figure** 1.40).

FIGURE 1.38
Coral reefs are among the most densely inhabited and diverse areas on the globe.

FIGURE 1.39
In this image of Maupiti Island in the South Pacific, the remnants of the volcano are surrounded by the circular reef.

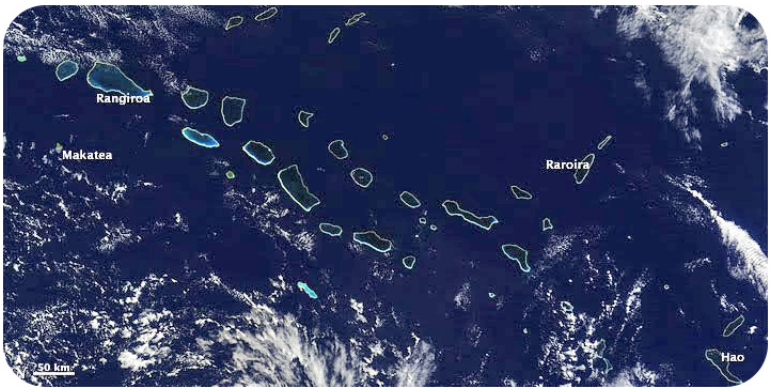

FIGURE 1.40
The Tuamotos are coral atolls that rest on volcanoes that are not beneath sea level.

Coral reef are near shore and so are subject to pollution from land. The coral animals are very sensitive to temperature and reefs around the world are stressed from rising ocean temperatures.

Some videos about threats to coral reefs are found at: National Geographic Videos, Environment Video, Threats to Animals, http://video.nationalgeographic.com/video/player/environment/

- Coral Reefs
- Belize's Coral Reef

Oceanic Zone

The open ocean is a vast area. Food either washes down from the land or is created by photosynthesizing plankton. Zooplankton and larger animals feed on the phytoplankton and on each other. Larger animals such as whales and giant groupers may live their entire lives in the open water.

How do fish survive in the deepest ocean? The few species that live in the greatest depths are very specialized (**Figure** 1.41). Since it's rare to find a meal, the fish use very little energy; they move very little, breathe slowly, have minimal bone structure and a slow metabolism. These fish are very small. To maximize the chance of getting a meal, some species may have jaws that unhinge to accept a larger fish or backward-folding teeth to keep prey from escaping.

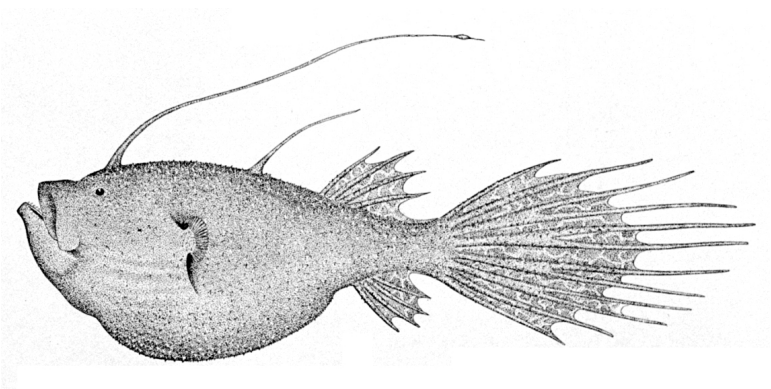

FIGURE 1.41
An 1896 drawing of a deep sea angler fish with a bioluminescent

Many ocean-related videos are found in National Geographic Videos, Environment Video, Habitat, Ocean section: http://video.nationalgeographic.com/video/player/environment/. Just a few are listed below.

- How we can know what lives in the ocean is in "Deep-Sea Robo Help"
- Some of the results of the Census of Marine Life have been released and are discussed in "Record-Breaking Sea-Creature Surveys Released"
- Bioluminescence is common in the oceans and seen in "Why Deep Sea Creatures Glow"

Hydrothermal Vents

At mid-ocean ridges at **hydrothermal vents**, bacteria that use **chemosynthesis** for food energy are the base of a unique ecosystem (**Figure** 1.42). This ecosystem is entirely separate from the photosynthesis at the surface. Shrimp, clams, fish, and giant tube worms have been found in these extreme places.

A video explaining hydrothermal vents with good footage is seen here: http://www.youtube.com/watch?v=rFHtVRKoaUM&feature=related.

Lesson Summaries

- The oceans have a tremendous diversity of life: bacteria, plankton, invertebrates, and vertebrates, which include fish, reptiles, seabirds, and mammals.

Tubeworms

FIGURE 1.42

Giant tube worms found at hydrothermal vents get food from the chemosynthetic bacteria that live within them. The bacteria provide food; the worms provide shelter.

- Photosynthesis and chemosynthesis create food energy in two very different ways.
- Plankton are tiny freely floating plants (phytoplankton) or animals (zooplankton).
- All marine organisms must be specialized for the harsh conditions of the ocean environment in which they live.

Review Questions

1. What is an invertebrate? Name two types.

2. What is the role of phytoplankton in ocean ecosystems?

3. If fish require oxygen to live, why can't they survive on land?

4. Are polar bears marine mammals or land animals like all other bears. What is your opinion?

5. What are four major habitats of ocean organisms?

6. Describe adaptations that an organism that lives in a reef might have. How might these adaptations be different from an organism that lives in the open ocean?

7. Describe the importance of maintaining the ocean ecosystems.

Points to Consider

- How does the ocean interact with the atmosphere?
- How is energy transferred around the planet and how does this affect life on Earth?
- What would be the effect of pollution on the oceans?

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