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THE RESTLESS EARTH

RIVERS, LAKES, AND OCEANS

GRETEL H. SCHUELLER

THE RESTLESS EARTH

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Earthquakes and Volcanoes
Fossils
Layers of the Earth
Mountains and Valleys
Rivers, Lakes, and Oceans
Rocks and Minerals

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1

Introduction: THE WATER PLANET

Water covers more than 70% of the Earth's surface. In fact, from space, our watery world looks like a glowing blue sapphire against the darkness of space. Roughly 326 million cubic miles (104 billion cubic kilometers) of water are found in the atmosphere, rivers, oceans, lakes, groundwater, and elsewhere. There is so much water in the world that if it was all poured on the United States, all the land would be under 90 miles (145 km) of water.

With so much of this liquid on Earth, it is no surprise that it affects our lives in important ways. Water makes life possible by, for example, providing freshwater to drink and for irrigating plants to grow food. That is why people in many areas have established their communities next to oceans, rivers, and lakes before moving out to populate the rest of the region. Even the land around you has been—in part—designed by water. Water may not seem very impressive when it is in your drinking glass, but it can cut routes through solid rock, destroy cities, and sculpt mountains and coastlines. Powerful moving bodies of water, such as rivers, change our landscape, creating valleys and even deep canyons over huge periods of time. For example, the powerful Colorado

Earth gets its nickname of "the blue planet" from the water that covers much of its surface. Most of the planet's liquid fills the oceans, which are visible from space.

River carved out the Grand Canyon in Arizona. The process took some 20 million years, but today the canyon averages 4,000 feet (1,219 meters) deep for its entire 277 miles (365 km).

MOVING WATER

The breaking down and wearing away of the Earth's surface by water is called **water erosion**. The scouring of a waterfall's edge is another powerful example of water erosion. In fact, over time, erosion causes a waterfall to move. For example, Niagara Falls lies midway along the Niagara River, which flows between Lake Ontario and Lake Erie. Ten thousand years ago, the waterfall was 7 miles (11 km) further downriver. Over time, the pounding water has gradually worn away the rocks at the edge of the waterfall, slowly moving it back. In about 25,000 years, Niagara Falls will disappear when it eventually reaches Lake Erie. Sometimes, the power of water can be destructive to people. Floods and **tsunamis**, for example, have devastated coastal communities. Tsunamis contain a huge volume of racing seawater in trains of

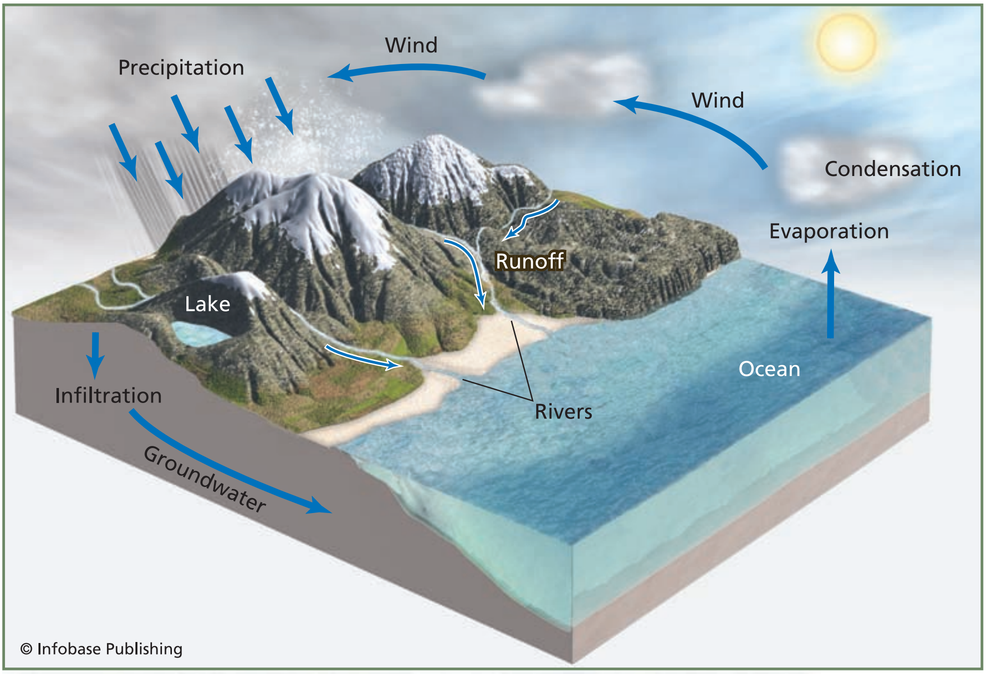
The majestic Grand Canyon in Arizona was cut over millions of years by the Colorado River. It is one of the most popular tourist destinations in the world, drawing millions of visitors each year.

giant waves. They can travel for thousands of miles across the open ocean at speeds of 500 miles (804 km) per hour, almost fast enough to keep up with a jetliner. These waves hit coastlines with enough energy to smash towns and drown people.

Fast or slow, all water is constantly on the move. The journey of a drop of water over time is far-flung and diverse. It floats through rivers, lakes, and oceans. It travels into giant glaciers and icy sheets of snow. It flies with raindrops in the sky, and it even seeps into the depths of the Earth as **groundwater**, which slowly trickles down through soil and rock cavities. Like a shape-shifting alien, water also changes form as it moves, from water vapor (gas) to liquid to ice (solid).

Moving Glaciers

Glaciers around the world are melting because of global climate change. Some are even moving. In fact, one glacier in Greenland went from standing still in 1996 to flowing at a rate of nearly 9 miles (15 km) per year by 2005, making it one of the fastest moving glaciers in the world. Glaciers appear to be flowing to the sea at faster speeds because their melting allows the ice to slide more easily over the rock and dirt underneath them. Glaciers react quickly to temperature changes. Scientists believe that Greenland's melting ice is going to cause sea levels to rise faster than they had first predicted. Eric Rignot, a glaciologist with NASA's Jet Propulsion Laboratory at the California Institute of Technology in Pasadena, and his colleagues found that in just 10 years, the amount of ice that had melted from the Greenland glaciers had more than doubled—from 21 cubic miles (90 cubic km) of total ice loss per year to 54 cubic miles (224 cubic km). That equals a lot of fresh water: The thirsty city of Los Angeles, California, uses only about 0.24 cubic miles (1 cubic km) of water in a year.



Water travels through an ongoing cycle, moving from place to place and changing states. Water in liquid form evaporates into gas form as water vapor, then condenses into either liquid or solid form as rain or snow. Liquid water can be stored for long periods of time in reservoirs, which include rivers, lakes, oceans, glaciers, and groundwater.

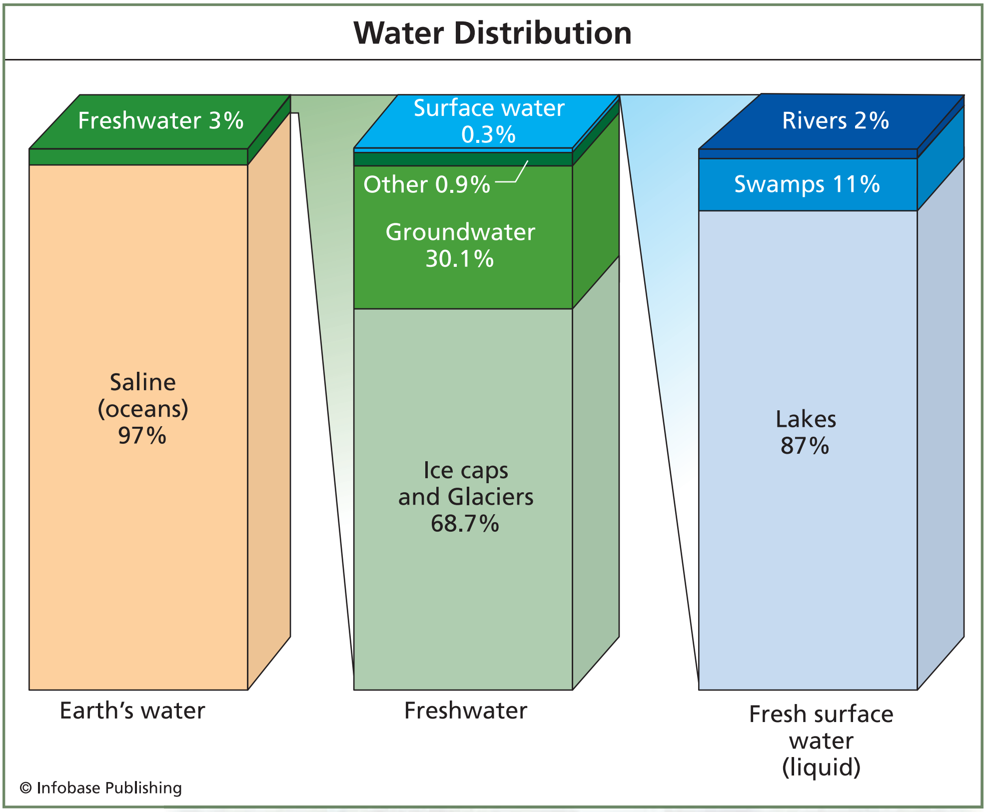
THE WATER CYCLE

Water also plays a role in our weather. In the skies above the United States, there are 40 trillion gallons (151 trillion liters) of water overhead on an average day in the form of clouds and water vapor. Each day, about 4 trillion gallons (15 trillion L) of this water fall to Earth as **precipitation**, such as rain, snow, or hail. More than half of that eventually returns to the atmosphere. The Sun's heat warms the water at the surface of lakes, oceans, and other bodies of water and turns it into water vapor; this process is called **evaporation**. The vapor rises into the air and strong winds take it thousands of feet above the surface, high into the atmosphere. Eventually, the vapor becomes cold and dense enough to form a cloud. When enough water or ice collects in a cloud, it rains. If the temperature is low enough, it snows. This endless circulation of water among land, bodies of water, and the atmosphere is called the water cycle, which is also known as the **hydrologic cycle**. As this cycle continues, the rain and snow that falls on land runs off into streams and lakes, or soaks into soil and rocks to become groundwater. Streams and rivers carry water downhill to lakes, and, ultimately, to the oceans. Surface water evaporates into the air as water *vapor*, or gas. It rises and forms clouds once again. Although you cannot see it, a huge amount of water vapor drifts through the sky at any given time. If all the water in the air fell at the same time, it would be enough to cover the entire Earth with one inch (2.54 centimeters) of water. Still not impressed? How about this: That same amount of rain would fill enough buckets—stacked on top of each other to make a giant tower—to reach from the Earth to the Sun. In fact, there would be enough water to build 57 million bucket towers between Earth and the Sun—the hard part would be finding enough buckets.

These huge amounts of water in the atmosphere move around quickly. In some ways, the atmosphere acts as water's "superhighway" because of how it carries water quickly across the globe in the form of clouds and water vapor that blow across the sky. Eventually, those clouds will become liquid again: Rain and snow fall and the cycle begins anew. Water takes many paths on its journey through the water cycle. Water in Lake Michigan might later fall as rain in New York. Runoff from that rain may drain into the Hudson River, where it will eventually flow into the Atlantic Ocean. From there, it could flow northeast toward Iceland, where it might, over time, become part of a giant glacier. On average, in a 100-year period, a drop of water spends a little over 98 years in the ocean, 20 months as ice, about 2 weeks in lakes and rivers, and less than a week in the atmosphere. As it travels through the water cycle, water passes through environments called **reservoirs**. The oceans, Earth's biggest reservoirs, supply most of the water for the water cycle. That's because most of the planet's water—about 97%— is in the oceans. It would take more than one million years for the oceans' total water supply to evaporate and pass through the air. Anyone following a drop of water on its journey from the deep ocean through the water cycle might be in for a very long trip!

The World's Biggest Aquifer

Ninety-five percent of the United States' fresh water lies underground. Worldwide, this groundwater is 40 times more abundant than freshwater in streams and lakes above ground. In the United States, half of the drinking water comes from groundwater. Although groundwater is a renewable resource, its reserves replenish slowly. Currently, groundwater in the United States is withdrawn at a rate about four times faster than it is naturally replaced. One crucial source is the Ogallala **aquifer**, a huge underground reservoir that stretches from Texas to South Dakota under about 174,000 square miles (450,000 sq. km) of land. This aquifer was formed over millions of years and once held more water than Lake Huron—before cheap electric pumps gave farmers the power to draw water from hundreds of feet below the surface. In some areas, the water level is falling 3 to 5 feet (0.9 to 1.5 m) a year. Unlike rivers, lakes, or even most other aquifers, the Ogallala has no source of replenishment. It holds "fossil water," which has been sealed underground for hundreds of thousands of years. Once used up, it is gone. Estimates for its remaining lifespan vary from 60 to 250 years. In some areas of western Kansas and northern Texas, usable water is already gone. Many farmers in the Texan High Plains, which rely on the underground source, are now turning away from irrigated agriculture as they become aware of the hazards of over-pumping.



Only a small percent of Earth's water is fresh, and an even smaller percent of freshwater is in liquid form. Saltwater in oceans makes up the majority of Earth's water.

Ice sheets located across the Arctic and Antarctic and mountain glaciers contain much of the remaining 3% of the world's water. This is freshwater, and most of it is currently frozen. Climate change continues to melt away the glaciers and the ice sheets, however. The freshwater that isn't frozen—about 30% of Earth's freshwater—lies out of sight below the surface as groundwater. Groundwater's main refill source is precipitation that seeps into the soil. As this water trickles downward, it fills up all the cracks and spaces between the soil and rocks. If you were to dig a well into such a waterlogged zone, you would hit groundwater. Sometimes, however, these reservoirs lie very deep in the ground. Reservoirs of easily available freshwater—namely rivers and lakes—account for only about 1% of the world's freshwater, and less than 0.02% of all water on Earth. To visualize how precious freshwater is, imagine a bathtub holds all of Earth's water. The freshwater readily available for human use would amount to only a tablespoon.

Nature's distribution of available freshwater, however, does not always correspond with the distribution of the world's population. Canada, for example, has 20% of the world's freshwater, but represents only 0.5% of the world's population. China, on the other hand, contains 21% of the world's people but has only 7% of its water supply. Sometimes, the most reliable sources of water exist far from where people need it most. For example, 60% of South America's Amazon River flows through remote rainforests where few people live.

Our Thirsty Demands

According to United Nations (U.N.) estimates, 1.2 billion people in the world do not have access to safe drinking water. By 2025, the U.N. estimates that some 3 billion people will suffer the effects of water shortages. Between 1990 and 1995, global water consumption increased six times, due, in part, to rising industrial demand. For example, it takes 80 gallons (300 L) of water to produce 35 ounces (1 kg) of paper. Changes in our diet also increase water consumption. It takes 15,000 tons of water to produce 1 ton of beef, while 1 ton of grain only requires 1,000 tons of water. Although the water supply within the global water cycle may remain constant, the quality of that water does not. In some regions, less and less water remains readily available for drinking because of pollution or because it runs off farmland into the oceans.

Surprisingly, even with all this moving and transforming, the total amount of Earth's water stays fairly constant. Most of the water on the planet today has been flowing through the water cycle for billions of years. The water that comes out of your tap today could be the same water that a dinosaur gulped out of a lake 170 million years ago. It also may have been snow on top of the Swiss Alps as recently as a few years ago. Like an international traveler, water is always on the go—flowing from mountaintops to the seafloor, dropping from clouds to lakes.

2

A River's Journey: SHAPING THE LAND

RIVERS ARE HUGE RIBBONS OF WATER THAT FLOW ACROSS THE LAND. The water in a river is water on a mission. Look at a detailed map, and you will notice how rivers and streams form a network of waterways across the countryside. Little streams meet to form small rivers. Small rivers join and become medium-sized rivers, which go on to connect with large rivers. They are all liquid highways—and very busy ones at that. On average, about 5,600 cubic miles (23,342 cubic km) of water flow down the world's rivers each year—enough water to cover all dry land in a layer 12 inches (30.5 cm) deep. What powers all this movement? The answer is gravity. Gravity causes rivers to flow from high to low ground. Looking at the profile, or side view, of a river, you would notice that rivers usually begin with a steep drop, then slope more gently, eventually flattening out by the time they reach their end. Scientists officially define a river as any natural stream of freshwater larger than a brook or creek that flows toward another river, an ocean, a lake, or other large body of water. Rivers can be thought of as excess water disposal machines. In places where it rains more, such as in a northern forest or a tropical rainforest, there are more rivers and streams to deal with the steady rainfall. In the desert, however, there is much less rain, so fewer rivers exist there. When it does rain in the desert, almost all of the water drains immediately into dry river beds that, for most of the year, look like flat plains. These rivers swell up very quickly and produce swift currents. Rain is one supply source for a river, but melting snow or ice, lakes, other streams, and underground springs that seep at the surface can all fuel a river. With the boost of one of these sources, water, at first, flows in tiny paths called **rills**, which might be just a few inches wide. These rills eventually join to form rivulets, which in turn come together to make creeks. Even huge rivers, such as the Nile in Egypt or the Amazon in South America, start from small sources like this. From its source, the river then follows the contours of the land, always going downward, thanks to gravity. Of course, a river's sources are not like a constantly running tap. The amounts of rain, snow, and groundwater can all vary. Therefore, a river also changes in size and rate of flow depending on how much water is feeding into it. In colder climates, melting snow is a major water source for rivers, especially during spring. In fact, a river can often be 20 times bigger in the spring than it is in the fall, when many rivers tend to run at their lowest level. For example, the North Fork of the American River in California has an average daily flow of 1,200 cubic feet (34 cubic m) per second in March; in August, its rate drops to as low as 55 cubic feet (1.6 cubic m) per second.

THE VOYAGE OF A RIVER

More than 3,000 years ago, the Chinese Emperor Yu said, "To protect your rivers, protect your mountains." That is because most rivers are born in the mountains. Anything that happens there will affect a river downstream. The area where a river starts its journey downward is called its **headwaters**. This is where a network of small upstream **tributaries**, small streams and creeks that eventually feed into a river, start to flow. As the water flows downstream, it grows in power and volume. More than 1,000 tributaries feed into South America's Amazon River, for example. All the land where precipitation runs off to feed a river and its tributaries with water is called a **drainage basin** (sometimes this area is also called a watershed).

Over time, rivers and streams change greatly in appearance. In fact, like people, they age. Flowing water creates currents that gradually wear away the sides and riverbed, or **channel**, of the river. Currents also move and mix matter, such as gravel, seeds, and plants. The speed at which those currents carve away at a river or mix together the substances that enter it is determined primarily by the river's age. Young streams tend to flow quickly and therefore erode the channel at faster rates. Mature streams

Underground Rivers

Rivers can also form underground in places where rocks become so full of water they cannot hold any more. The top level of this soggy rock is called the **water table**. Rainwater is acidic, and as it seeps underground, it dissolves, or eats away, soft rock, such as limestone. Eventually, the gaps formed by this process grow into caves and tunnels, through which rivers flow. A river will reappear at the Earth's surface if the water table reaches ground level—often in the form of a spring. In a labyrinth of caves on Mexico's Yucatán Peninsula, divers discovered a 95-mile-long (153 kilometer) underground river. Carving its way through the region's "spongy" limestone, it appears to be the longest underground river in the world. The Yucatán Peninsula is largely made of limestone, a soft and porous rock that is easily eroded by slightly acidic rainwater that carves out underground passages as it courses toward the Caribbean Sea. The pathways range from rooms the size of a jumbo jet to narrow slits where divers must squeeze to get through. Before this river's discovery, the Palawan River in the Philippines and Vietnam's Son Trach River were vying for the record as the world's longest underground river.

move slower, and the speed of their currents depends more on how steep the surrounding land is. Rivers flowing on flat land move slowly. For example, the Mississippi River, on its journey through the southern tip of Louisiana to its final destination in the Gulf of Mexico, moves so sluggishly that people sometimes call it "Old Man River."

Viewed from the sky, a typical river system looks like a tree with many branches. A single river can be divided into three main parts: the upper river, the middle river, and the lower river. The first part starts at the source of the river, at the headwaters, and is called the upper river. This portion often flows through mountains where there are steep, V-shaped valleys, rushing water, and many narrow streams. The steeper the slope, the faster the water runs. On a sharp slope, the river cuts down into the land. It takes up most of the narrow valley floor and winds its way around obstacles. Typical features of an upper river valley are **interlocking spurs**, "tongues" of land that rise from the valley. The river zigzags around these spurs because they are made of rock that is too hard for the water to wear away. From above, these spurs look like the teeth of a zipper.

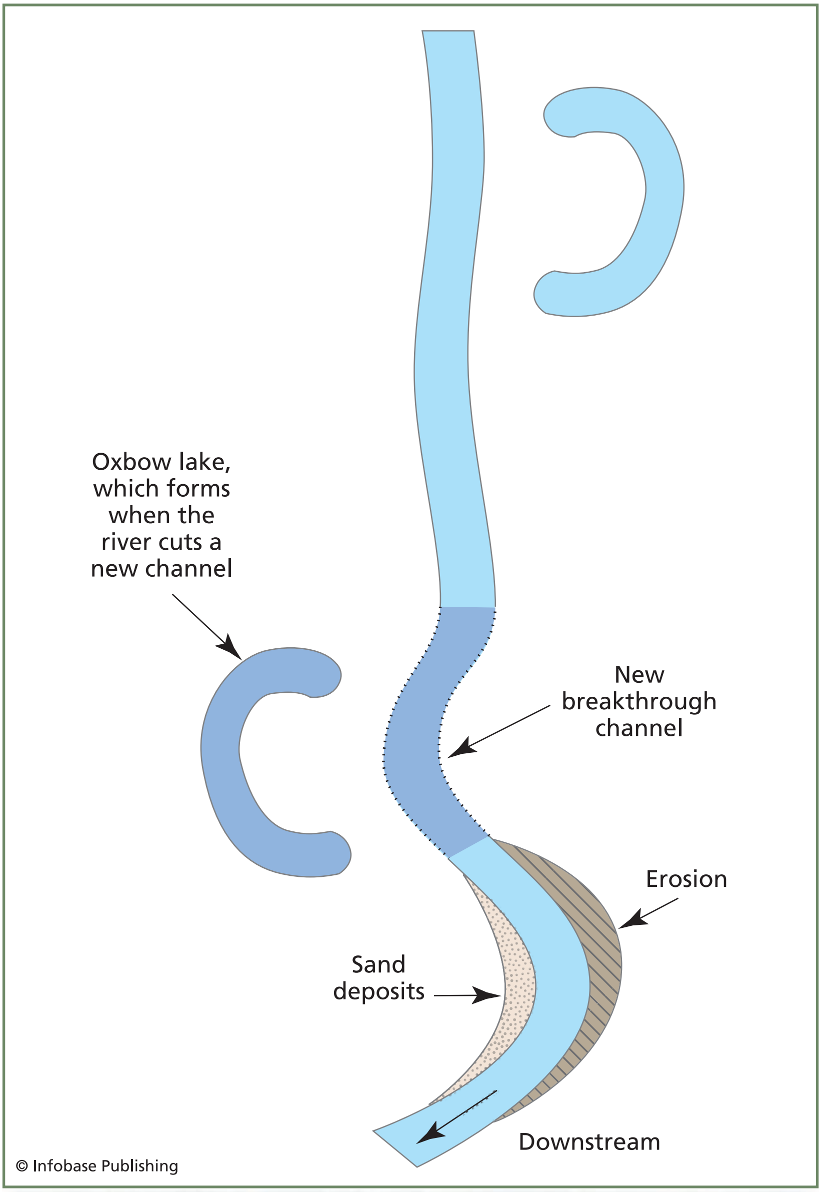
In mountainous regions where there is a lot of sand and gravel, a river must thread its way around bars of sand, gravel, and other coarse sediment. Called **braided rivers,** these interweaving channels look much like braids in someone's hair.

The second section is called the middle river. Here, the profile is less steep. The valley is wider—and so is the river. The reason is because the river starts to carve sideways into the land, rather than downward. The V-shaped valley has turned into a flat-bottomed valley, leaving straight-sided bluffs along the valley sides. As the river travels farther from its source, more tributaries join it, and the amount of water increases. The water flows fastest in the center of the river channel near the surface where there is the least friction. The greatest wear exists along the sides where water eats away at the edges. For this reason, the river at this point also carries more sediment—sand, gravel, mud, and fine **silt**—than it did in the upper river. (In fact,

Braided rivers usually form in regions where there is a lot of sand and gravel. The Waimakariri River flows through Canterbury Plains, New Zealand.

rivers carry away about 22 billion tons of sediments each year.) A smooth layer of mud and silt blankets the riverbed.

The path of the middle river is always changing. It erodes soil along the side in some areas and deposits sediment in others. This movement of sediment can reshape the river, causing it to twist and turn. Large curves in a river's course are known as **meanders**. These curves tend to form where there are wide, strong riverbanks.



A meander forms when a river erodes away one side of a riverbank and deposits sediment on the opposite side. As a meander grows increasingly curved, the river cuts a new channel that is shorter and faster, leaving behind an oxbow lake, a horseshoe-shaped lake that is separate from the river.

A meander grows bigger over time: The more a river cuts away material on one side of its bank—shaped like the outside of a *C*—the more material it leaves on the other side—shaped like the inside of the *C*. Typically, where the material is deposited on the inside of the curve, a sandy beach grows. Eventually, a meander can grow so wide that it practically becomes the shape of the letter *O*; only a narrow strip of land separates the sections of the river. Eventually, the river cuts through this strip, forming a straighter, new channel. It leaves behind a horseshoe-shaped lake called an **oxbow lake**, which will slowly fill in with plants.

The last stage is the lower river. Near the end of its journey, the river travels leisurely over an extensive, flat plain. This broad valley can be many miles wide. This flat region is called a **floodplain**. Here, rivers deposit fine mud on the riverbed and banks. Some of this builds up to form taller, wall-like banks called natural **levees**. A heavy rain, or snow melt from the mountains, will suddenly pour more water into the river. When this surge of water reaches the lower river, the river may burst its banks and overflow, spreading mud all over the floodplain. Many people live on floodplains despite the risk because the land is so fertile, thanks to the rich buildup of mud and silt, which contain minerals and nutrients for plants. Sometimes an "old" river can be made young. This happens when the slope of a river suddenly increases because the earth moves and lifts. As a result of this steeper landscape, the river gains more energy and carves a narrower and deeper channel. The old floodplain sits at a higher elevation, looking like steps. When this happens, **river terraces** form. When the terraces on both sides of a river channel are of the same elevation, they are called "paired terraces." The river's end is called the **mouth**. Most rivers end their journey when they flow into a sea or lake. The river's speed winds down, and it starts to drop all the sediment it was carrying. Heavy grains of sand and gravel fall first. Lighter particles of silt and clay flow further out to sea, or into the lake.

Gradually, the sediments fan out to form a new plot of land with gently sloping sides called a **delta**.

There may be many parts to a river, but they are all connected. Picture it this way: If a rubber duck were dropped into a high mountain stream on Pike's Peak in Colorado, it would tumble down the rapids to the old mining town of Cripple Creek. From there, the duck would rush over gravel beds where Colorado miners once panned for gold, and then meander serenely across Kansas, Oklahoma, and Arkansas on the Arkansas River. Then it would plunge through the spillways of several dams before entering the muddy waters of the Mississippi River. A few weeks or months later, that duck might be spotted leaving New Orleans and entering the Gulf of Mexico, floating among barges and riverboats.

HUMANS AND RIVERS

Rivers have always been important for travel, transportation, and trade. Many settlements were built along major rivers. Rivers are also important for farming because river valleys and plains provide fertile soils. Farmers in dry regions irrigate their cropland using water carried by irrigation ditches from nearby rivers. Rivers also are an important energy source. In the 1800s, mills, shops, and factories were built near fast-flowing rivers where water could be used to power machines. Today, steeply running rivers are still used to power hydroelectric dams and their water turbines. Although rivers offer many benefits to people, they can also be dangerous. When rivers flood, they can destroy crops and buildings; sometimes, they can even cause death.

No other natural force changes as much of the world's surface as does running water. In fact, the world's rivers could completely erode the face of the Earth, although it might take 25 million years to do it. The mighty Amazon River, for example, is so powerful that it carries sediment 60 miles (97 km) out to sea. This sediment is visible as a muddy-yellow plume of water. As water flows through a river channel, it pushes into cracks and crevices, breaking off bits of rock and mud. Those bits of sediment, in turn, scratch and scrape against more rocks and soil in the channel, causing even more sediment to erode away. A river carries all of this material in three ways. Large bits of stone and gravel tumble and roll along the riverbed, much like a powerful

Three Gorges Dam

The world's biggest dam is the Three Gorges Dam in China. At 1.5 miles (2.4 km) wide and more than 600 feet (183 m) high, the massive concrete structure stretches across the Yangtze River, the third longest river in the world behind the Nile and the Amazon. Many Chinese believe the Three Gorges will be an important source of energy for China's growing electricity consumption. The Chinese government estimates that electrical power derived from the dam's turbines will provide up to one-ninth of China's demands. It is also expected to tame the fabled Yangtze River, whose massive floods have claimed more than one million lives in the past 100 years alone. The dam, however, has many critics. When fully functional, this hydroelectric dam will create a reservoir hundreds of feet deep and nearly 400 miles (644 km) long. The Three Gorges Reservoir will submerge 244 square miles (632 square km) of land. As a result, more than 1.4 million people have had to move to new homes, and more than 1,200 towns and villages have disappeared under its rising waters. Environmentalists worry that by severing the mighty river and slowing the flow of its water, the dam will cause pollution from homes and factories to concentrate in the river. The rising water has already caused widespread soil erosion. The erosion of riverbanks has led to collapses and landslides along the shores of the Yangtze's tributaries. In addition, archaeologists say many important ancient sites will disappear under the reservoir's waters.

hose can push along a ball or pile of leaves. Fine particles of sand and silt float suspended in the water, just like the "snow" in a shaken snow globe. And some particles, such as the minerals calcium and sodium, are so small that they completely dissolve in the water, similar to what happens when sugar is mixed into a drink. We see the handiwork of rivers all around us in ways both big and small. The Grand Canyon, with its 30-million-year history of being carved by the Colorado River into a mile-deep canyon, is one of the largest examples.

And then there are the smaller scale examples, such as potholes. These form when swirling currents of water carrying gravel and pebbles drill out circular hollows that range in size from a sink to a couch. This liquid drilling can even dig into hard rock over time.

Waterfalls are another example of a river's land-sculpting powers. A waterfall forms when a river flows over hard rock onto soft rock. The soft rock, of course, is easer to wear away. As a result, over thousands of years, the soft rock disappears, leaving behind a higher step of hard rock. The river plunges over the band of hard rock, carving out a deep pool as it hits the soft rock below. The highest waterfall in the world is Angel Falls in Venezuela, where water plunges from a height of 3,212 feet (979 km).

The whitewater rapids that are popular with some kayakers, rafters, and tubers are another example of what happens in places where hard and soft rock alternate over a shallow, rocky riverbed. In this case, bands of hard rock tilt at an angle, making a series of miniature waterfalls, a few feet high at most. The rocks break up the flow and churn up the water to make it frothy. Bobbing over whitewater might be fun, but living through a river flood is not. In a large flood, a river can be ten times deeper than normal. Heavy rains are one cause of a flood. Clear-cutting a forest, which keeps water from soaking into the soil and thus causes erosion, is another cause of flooding. In many places, people try to control rivers in order to prevent floods. Building concrete levees, or walls, along a riverbank is one common solution. Many river channels have also been dredged to make them deeper and wider

Angel Falls in Venezuela is the world's highest waterfall. It is a prime example of the eroding force of rivers.

Many communities along the Mississippi were flooded when the mighty river's banks overflowed in 1993.

so they can hold more water and thus prevent flooding. One of the world's most heavily controlled rivers is the Mississippi River system, a huge network of rivers and streams that drains water from the North American Plains between the Rocky Mountains and the Appalachians. The Mississippi River and its tributaries, which include the Ohio, Missouri, and Arkansas rivers, are the central water arteries of the Midwest.

Whatever people might try to do to contain them, it seems rivers always fight back. In 1993, the Mississippi River showed off its force—with deadly consequences. It began with rain, and lots of it. The torrential showers, which had begun in the spring, returned in June and continued to fall on the already soaked fields. The waters of the Mississippi, Missouri, and Illinois rivers and their tributaries soon spilled over once-protective levees. The flood was one of the most significant and damaging natural

River Fun Facts

- The United States has more than 250,000 rivers. That's 3.5 million miles (5.6 million km) of rivers.
- More than 25,000 miles (40,200 km) of rivers have been dredged for navigation in the United States.
- According to the U.S. National Park Service, currently 600,000 miles (966,000 km) of U.S. rivers lie behind an estimated 60,000 to 80,000 dams.
- In the United States, the largest river is the Mississippi, which has a flow volume of 593,000 cubic feet (16,800 cubic m) per second at its mouth, and is 2,340 miles (3,766 km) long. The longest river is the Missouri, which flows for approximately 2,540 miles (4,087 km).
- The world's longest river is the Nile River in Egypt. It flows 4,145 miles (6,670 km) from its source in central Africa to its mouth on the Mediterranean Sea.
- The world's biggest river in terms of water volume is the mighty Amazon River. It starts in the snows of the Andes Mountains in Peru, travels through a vast rainforest, and ends 4,000 miles (6,437 km) later on the Atlantic coast. The Amazon's flow of water comprises one-fifth of all river water.
- Most, but not all, rivers end up in an ocean: The rivers that flow south from the Tassili Mountains in North Africa slow down to a trickle and then disappear into the dry sands of the Sahara Desert.

disasters ever to hit the United States. Some locations on the Mississippi River were flooded for almost 200 days, while locations along the Missouri neared 100 days of flooding. The flooded area totaled about 30,000 square miles (78,000 square km). Damages totaled $15 billion, 50 people died, hundreds of levees failed, and thousands of people were evacuated from their homes; some of them were forced to stay away for months. In June 2008, fed by heavy rains, the swollen Mississippi burst its banks again, rivaling the force and damage of the 1993 flood.

Rivers are like the arteries of the planet. They transport water and soil from mountaintops to lower land. As rivers flow across the landscape, their personalities change. Sometimes they are lazy, simply flowing the path of gravity. Other times, they are a force to be reckoned with, bursting over banks, flooding whole cities, and changing entire landscapes.

3

Water's Rest Stops: LAKES AND PONDS

IF RIVERS ARE THE HIGHWAYS FOR WATER, THEN LAKES AND PONDS ARE the temporary rest stops. Lakes form wherever water settles in a depression, or a low spot, on a surface. They can form anywhere in the world—even under frozen glaciers and in caves. Their water comes from rainfall or melting snow, and much of it flows in from streams or rivers. Most lakes are full of freshwater and have at least one river flowing out. Lakes come in all shapes and sizes. The largest lake in the world is the Caspian Sea, a saltwater lake that lies between Europe and Asia. Its surface area of 143,250 square miles (371,000 sq. km) makes it even larger than all five Great Lakes combined. One of those Great Lakes, Lake Superior, however, earns the title for the largest freshwater lake in terms of area: It is 31,700 square miles (82,103 sq. km). Lake Baikal, in eastern Russia, is the world's deepest lake, at 5,315 feet (1,620 m). It holds 20% of the world's fresh surface water and is the world's largest freshwater lake by volume. One reason Lake Baikal contains so much water is that the 336 rivers flow into it, while only one river flows out.

Lakes Under Ice

Antarctica is the coldest spot on Earth. Temperatures can fall to –132° Fahrenheit (–56 ° Celsius). A flat, empty snowscape of pure white stretches across the surface. Several perpetually ice-covered lakes—frozen solid—do exist on the surface, such as Lake Hoare. It was once thought that the Antarctic continent was too cold for water to exist in liquid form beneath its frozen shell of snow and ice. Since the 1960s, however, satellites and aircraft with powerful radar devices have discovered many liquid lakes buried miles beneath the thick ice sheet. So far, scientists have found more than 150 freshwater lakes, but there could be thousands. The largest Antarctic lake is known as Lake Vostok and it is about the size of Lake Ontario—155 miles (250 km) long, 25 miles (40 km) wide, and 1,300 feet (400 m) deep. In a place where there is nothing but snow and ice, the lake even has a thick layer of sediment covering its bed. These lakes sit at least a couple of miles below the top of the ice field. Even though it is below freezing in Antarctica, the immense pressure of the ice above keeps the water in liquid form. Rivers that also run under the glaciers feed these unusual lakes with water. These subglacial rivers and lakes are believed to play a key role in the movement of glaciers. Like grease on a bike chain, the water under the ice sheets lubricates the glaciers and aids their movement toward the ocean.

These underground lakes are sealed off from the surface, took millions of years to form, and have remained undisturbed. For these reasons, these lakes are like time capsules of the period when the continent began to freeze over. Some scientists believe that new and unusual species of animals may be found trapped under the ice.

TYPES OF LAKES

Lakes are categorized based on how they formed. Glaciers, for example, are responsible for many bowl-shaped lakes known as **erosion lakes**. These lakes formed when glaciers scooped out round depressions in the rock that eventually filled with water as the glaciers retreated some 20,000 years ago. The Great Lakes of the Midwest and the Finger Lakes of New York are examples of erosion lakes. Many lakes in northern areas are also a legacy of glaciers. (Nearly half of the world's lakes are located in Canada.) Glaciers are also responsible for the creation of **barrier lakes**. As a glacier moves across the land, it scrapes off rocks, mud, sand, and other material, pushing it along. When the glacier melts, it leaves behind a tall ridge of glacial debris that prevents water from flowing away and so forms a lake. Small lakes and ponds also formed in glacial depressions called **kettles,** which were created as blocks of ice that had been buried in glacial sediment melted.

Minnesota is known as "the land of 10,000 lakes." This is no exaggeration: There are 11,842 lakes over 10 acres (.04 square km) in size in the state—most of them located in the northern part. Almost all of them owe their origins to glaciers. Even so, Minnesota does not rival the lake plateau of Finland, a country with so many barrier lakes it is called "the land of 40,000 lakes." **Tectonic lakes** form when a block of land slips down to create a deep crack; these lakes tend to be long, narrow, and quite deep. Lake Baikal is one example of this kind of lake. It is no surprise that the second-deepest lake in the world is also a tectonic lake: At more than 5,200 feet (1,600 m) in depth, Lake Tanganyika in eastern Africa is the second-deepest freshwater lake in the world. It is one of several very old and deep lakes that have formed along Africa's Great Rift Valley. In regions with wet climates, water moving underground often rises to the surface because the water table is high. Groundwater eats away at limestone and other rocks, creating, among other things, sink holes and basins.

Well over 10,000 lakes dot the landscape of Minnesota. These lakes were formed by glaciers that carved depressions in the earth as they retreated millions of years ago.

Florida's many lakes, including Lake Okeechobee, are groundwater-filled sinkholes. These are called **groundwater discharge lakes.** In the Arctic, a layer of dirt that lies just beneath the surface remains frozen year round, keeping water from seeping into the ground. As a result, the water collects in depressions on the surface. This frozen layer of ground is called permafrost. In recent years, however, warming temperatures have caused some of these lakes to disappear in places where the permafrost is

Volcanic lakes, such as this one on Mount Tongariro in New Zealand, form in active volcano craters and are typically tinted green by volcanic gases and acidic water.

melting. People—along with beavers—are also responsible for some lakes. When people build a dam across a river, a long lake forms behind the dam. One famous example, Lake Mead, rests behind the Hoover Dam along the Colorado River. It stretches more than 100 miles (161 km) through the desert.

The most exotic type of lake is perhaps the **volcanic lake**. These bodies of water form when rain and melting snow fill the craters of volcanoes. Mount Tongariro in New Zealand has

A crater lake that forms in the crater of a dormant or extinct volcano usually contains clear, fresh water. Crater Lake in Oregon is a well-known lake of this kind. Wizard Island, in the center, was formed in a volcanic eruption thousands of years ago.

several big and small volcanic lakes. The water within them is quite acidic, saturated with volcanic gases, and cloudy with a strong greenish color. This is typical of lakes on top of active volcanoes. While many volcanic lakes are picturesque, they can also turn deadly. Carbon dioxide explosions from Lake Nyos in Cameroon, a nation in Africa, suffocated 1,800 people in 1986. Lakes located in dormant or extinct volcanoes, on the other hand, tend to have freshwater. They also have some of the clearest water in the world because they have no streams or sediments flowing into them. One of the best known is the appropriately named Crater Lake in Oregon. It has an intense blue color and crystal-clear water. It lies inside a volcanic basin that was created when the 12,000-foot (3,660 m) high Mount Mazama volcano collapsed 7,700 years ago following a large eruption. Generous amounts of winter snow, averaging 533 inches (1,354 cm) per year, supply the lake with water. There are no inlets or outlets to the lake. Crater Lake, at 1,943 feet (592 m) deep, is the seventh-deepest lake in the world and the deepest in the United States. Two "leaks," evaporation into the atmosphere and seepage into the ground, prevent the lake from getting any deeper.

SALTWATER AND FRESHWATER

Most lakes are freshwater, but there are some lakes that are as salty as, or even saltier than, the ocean. The Dead Sea, on the border between Israel and Jordan, for example, is Earth's saltiest body of water—so salty that fish cannot live in it. Salt lakes tend to form in dry regions where evaporation happens quickly. Evaporating water leaves behind dissolved minerals, including salts. Over time, as evaporation continues, the lake becomes saltier. Some salt lakes, such as Utah's Great Salt Lake, are all that remain of much larger freshwater lakes that have evaporated over a long period of time. The Great Salt Lake is about three to five times saltier than the ocean and supports only a few species of salt-loving fish and shrimp.

On the other hand, the Caspian Sea began life as a saltwater-filled ocean basin that closed about 5.5 million years ago. The sea has numerous tributaries, however—notably the Volga, Ural, and Zhem rivers—so it is not growing saltier. Its **salinity** (a measure of the concentration of salt in water) is about one-third that of seawater.

DISAPPEARING WATER

One thing that all lakes do have in common is that they do not last forever. In fact, it is the fate of all lakes to eventually disappear—the water evaporates, it is drained away by rivers, or it fills

A Shrinking Lake

Until about 40 years ago, Muynak, a town in Uzbekistan, was a busy fishing port and lakeside resort on the Aral Sea. Boats brought in loads of fish. Today, the waters have receded so much that there is not a drop as far as the eye can see from Muynak, only sand stretching to the horizon and beyond. What looks like snow is really salt.

In fact, until recently, the Aral Sea was the fourth-largest lake in the world, covering 26,000 square miles (67,000 sq. km) and containing 264 trillion gallons (999 trillion L) of water. Now almost all of it has gone, leaving 19,000 square miles of salty desert. The United Nations estimates that every day, the wind blows roughly 200,000 tons of salt and sand from the barren lake bed and dumps it within a 186-mile (300-km) radius, destroying the surrounding farmland. Beginning in the 1960s, farmers and state officials in Uzbekistan, Kazakhstan, and other Central Asian states started diverting water from rivers that fed into the lake, siphoning off millions of gallons to irrigate cotton fields and rice paddies. Up to that time, two rivers, the Amu Darya and Syr Darya, fed the lake with some 16 cubic in with soil and plants. Compared to oceans, which are older than 100 million years in many regions, lakes are infants. The world's oldest lake is Russia's Lake Baikal, and its history goes back some 25 million years. Most lakes are much younger. The Great Lakes, for example, are about 20,000 years old. The lives of many lakes can be measured in thousands of years. Lakes are relatively young because they are temporary features. Earth scientists who study lakes see them as temporary reservoirs within the stream and groundwater system. All water that falls as precipitation on land eventually makes its way back to the ocean or evaporates into the atmosphere. Water collects in lakes because it enters faster than

miles (65 cubic km) of water each year. The Amu Darya River, once considered the Mississippi of central Asia, is today a mere trickle. And the Aral Sea is now a fourth of its former size, and mostly devoid of any life.

When the Aral Sea began to retreat, boats that were once part of a vibrant fishing industry were abandoned on dry land.

it can escape, but it is not permanently trapped there. Just like a tub with a running faucet and an open drain, drops of water are constantly entering and leaving. After its arrival at a lake, an average water drop spends about 100 years there before moving to a new location. Lakes that fill depressions and have no outlets grow larger when the climate becomes wetter or when warm periods melt mountain snows. During dry periods, however, they evaporate away. It might take thousands, or even tens of thousands of years, but lakes eventually drain, fill in with sediment, or dry up. Smaller lakes typically fill in because of erosion. Lapping waves may gradually cut into a lake's edge at the waterline. The soil breaks loose from the constant beating of the water and falls into the lake. Steep banks can form. Then the erosion process speeds up. Water wears away at the bottom of the bank, creating ledges of soil that topple into the lake. Plants that grow at the edge of a lake can slow down the process of erosion because their roots help hold the soil together. Over time, rivers can also fill a lake with sediment. A river can carry dissolved or suspended soil particles for miles until it reaches a lake where it dumps everything.

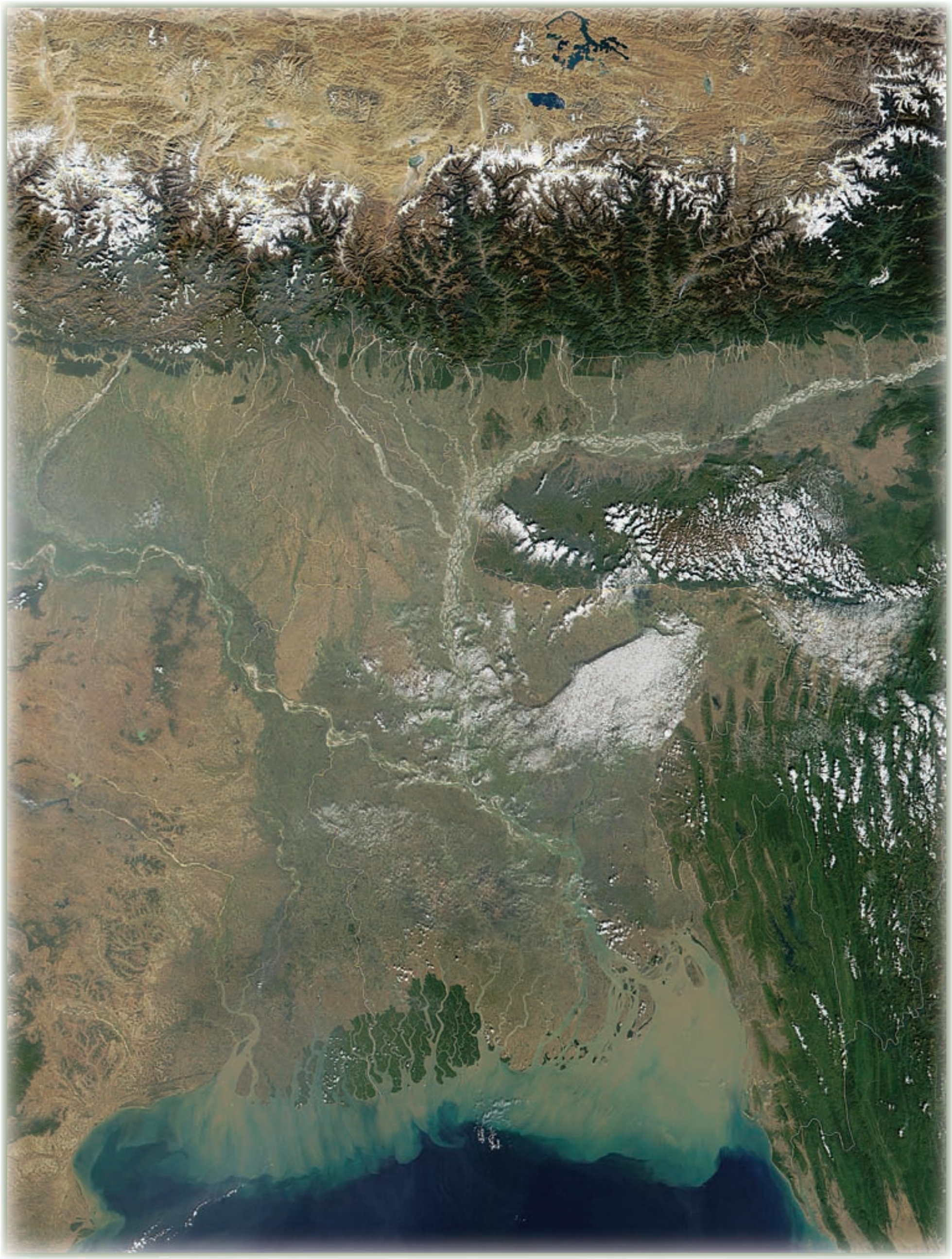
Like rest stops along a highway, lakes provide temporary resting areas for water. Of course, sometimes those breaks may last thousands of years. But eventually, the water will move on, seeping into the soil, evaporating into the atmosphere, or flowing into a river—and the lake, too, will disappear.

4

Where the River Meets the Ocean: A MIXING OF WATERS

WHEN A RIVER FINALLY MEETS THE SEA, IT FLOWS INTO A WHOLE NEW watery world. For the first time, fresh river water mixes with salty ocean water. Just before they enter the ocean, rivers tend to widen and go off course, branching into many directions and creating many small islands in the delta region. These branching channels are called **distributaries.** By the time the mighty Mississippi River spills into the Gulf of Mexico, for example, it has grown to more than one mile wide. The Ganges River delta, in Bangladesh, is the world's biggest delta. The Ganges River has eight main distributaries and hundreds of smaller ones. From the sky, it looks like a twisted maze of creeks and channels. Fed by seasonal heavy rains called monsoons and by melting snow from the Himalayan Mountains, the Ganges and another river, the Brahmaputra, join in Bangladesh and then fan out into the 220-mile (350-km)-wide Ganges Delta before emptying out into the Bay of Bengal. Both of these rivers deposit a huge amount of sediment in and around the delta. During a flood, it can amount to as much as 13 million tons per day.

Almost the entire Ganges Delta is dotted with lakes, marshes, and low-lying swamps. The southwestern portion of the delta



The deltas of the Ganges and Brahmaputra Rivers combine at the shore of the Bay of Bengal. This photograph was taken from a satellite orbiting Earth.

is largely covered with mangroves, trees that can grow in salty water. Their long, tangled roots anchor them in the shifting mud and help reduce water erosion by holding the soil together. This swampy forest is known as the Sunderbans. It is home to the endangered Bengal tiger. With so much of the land underwater, this tiger has learned to become a powerful swimmer. The delta is also home to most of Bangladesh, one of the world's most densely populated countries. Deltas provide some of the richest, most fertile farmland in the world, thanks to all the nutrient-rich sediment that the rivers bring to them. Roughly 120 million people live on the Ganges Delta in spite of the threats from repeated catastrophic floods. Heavy meltwater from the Himalayas and intense rains during the monsoon season cause the rivers to spill over and flood huge areas of the coastland. Together, both the Ganges and the Brahmaputra rivers pour as much as 2.9 million cubic feet (82,000 cubic m) of water per second into the Bay of Bengal.

All deltas are shaped by the interactions of the river's freshwater with the ocean's saltwater and waves. In the fifth century B.C., the Greek historian Herodotus coined the word delta to describe the triangular shape of sediment deposits located at the end of the Nile River. (The capital Greek letter *delta*, Δ, resembles a triangle.) Many deltas are triangular because rivers deposit large amounts of sediment when they first meet the sea—the "top" of the triangle. Then they fan out to deposit the remaining lighter sediment. The biggest sediments, such as gravel and pebbles, are deposited closest to shore. The smallest bits, such as silt, float far out into the ocean. In most deltas, river water is less dense, or packed together, than seawater because it contains less salt. As a result, river water floats on top of the salty water as it flows out into the ocean. This is called **hypopycnal flow**. (The prefix *hypo* means under, or less, and the root word *pycn* means density.)

TYPES OF DELTAS

There are three main types of deltas: river-dominated, wave-dominated, and tide-dominated. Each type has a distinct pattern

Some river deltas, such as the Mississippi Delta where it empties into the Gulf of Mexico, form a "birds foot" when sediment builds up, forcing the water to find new routes to the ocean.

of its distributaries. River-dominated deltas extend outward from the coast as the river water jets out into the ocean. They tend to have just a few major distributaries—sometimes only one—near their mouths. River-dominated deltas often have long deposits of sand called **sand bars** that run perpendicular to the river.

Currents carry the sediment away as it exits the mouth. As the currents travel into the ocean—typically parallel to the coastline—they deposit sediment along the way, and the delta grows long and thin like a bird's foot. In fact, these types of river-dominated deltas are often referred to as "Bird's Foot" deltas. The Mississippi River Delta in Louisiana is an example of this type.

Arcuate, or fan-shaped, deltas have many active, short distributaries that take sediment to the river's mouth. As the sediment exits these distributaries, there are few currents, so waves push it back. As a result, the coastline is rather smooth and shallow. The Nile River Delta is an example of a wave-dominated delta. Another type of wave-dominated delta is the cuspate, or tooth-shaped, delta. It usually has one distributary emptying into a flat, shallow coastline with wave action meeting it head-on. The waves tend to push the sediment back on each edge of the mouth, causing a "tooth" of sediment to grow in the middle. Italy's Tiber River Delta, which empties into the Mediterranean, is an example of this type.

In tide-dominated deltas, sediments deposited by the river are redistributed by the ocean's **tides**. These deltas have channels cut by river water as well as by tidal currents. The result is a shoreline that looks like the fringe on the end of a carpet. The Ganges Delta is one example.

Not all rivers form such vast, complex deltas. For deltas to form, the rate of sediment deposition has to be higher than the rate of removal by waves and currents. In places where sediment does not build so quickly—typically along coastlines where the ocean tides are strong—rivers and oceans meet to create an **estuary**, a mixing zone of freshwater and ocean water. The resulting blend has a salinity that is neither freshwater nor seawater. This type of water is called **brackish**.

ESTUARIES

Estuaries and the soggy lands surrounding them are places where land transitions to sea. They are often called bays, lagoons, harbors, inlets, or sounds—though not all bodies of water with those names are necessarily estuaries. The defining feature of an estuary is the mixing of freshwater and saltwater. Some examples of estuaries include San Francisco Bay in California, Puget Sound in Washington, and Chesapeake Bay in Maryland, which is the largest estuary in the United States. Estuaries often exist where the opening to the sea is blocked slightly—for example, by a sandbar or a **lagoon** (a body of shallow water separated from the ocean by sandbars or coral reefs). They are protected from the full force

A Restless Delta

In some places, human engineering can actually undo a river's work. The system of dams, channels, and levees that were built along the Mississippi River stopped the natural process of rebuilding the river delta with rich sediment deposits. As a result, land in this area is disappearing faster than it is being created. Since 1932, the Mississippi River Delta Basin has lost approximately 70% of its total land area. Louisiana is currently losing about 25 square miles (65 sq. km) of coastal land every year. Rewinding through the last 10,000 years of the Mississippi River would reveal a river prowling restlessly along Louisiana's 400-mile (644-km) coastline, changing positions almost overnight in a constant search for a path of least resistance in the form of the lowest-lying land and the shortest route to the Gulf of Mexico.

From 7,500 years ago until about 5,000 years ago, the Mississippi contented itself with a westward course and emptied into the gulf on the Texas side of where New Orleans now sits. Then, 5,000 years ago, the river swung eastward and charted a new course on the eastern side of what would one day be New Orleans. This eastward orientation lasted until about 2,000 years ago, when the Mississippi switched tracks and again swung back. This westward of ocean waves, winds, and storms by various landforms. Because it has very little wave action, an estuary provides a calm refuge from the open sea.

The part of the estuary farthest from the ocean is often where you will find a **salt marsh**, which is a wetland dominated by reeds and grasses. Water usually flows through salt marshes in **tidal creeks**. Unlike rivers, the water in a tidal creek flows in two directions—toward the ocean and toward the river. A little

sweep would have eventually moved the Mississippi well past New Orleans, except that the levees and dams, built by humans in the past two centuries, now force the river to flow through New Orleans to the Gulf of Mexico. As a result, the ground on which New Orleans sits is now sinking 3 feet every 100 years. Many of the city's neighborhoods lie 11 feet (3.4 m) below sea level. This is because the Mississippi deposits tons of heavy, water-soaked sediment daily into the Gulf of Mexico. As the sediment piles up, it is compacted by its own weight and squeezes out its water, causing the shoreline to sink—much like pushing down on a wet sponge. A thick layer of salt that coats the floor of the Gulf of Mexico several thousand feet below sea level also helps increase the sinking process: Oozing like toothpaste, the salt is flattened by the weight of the overlying sediment, causing even more sinking. Meanwhile, a short distance to the west, the delta region of the smaller Atchafalaya River is also sinking—in fact, the entire Louisiana coastline is sinking, due in part to tons of sediment deposited thousands of years ago, which is slowly squishing down the land. The Atchafalaya deposits little sediment. Normally, the Mississippi River, yielding to gravity, would shift course and fill the sinking Atchafalaya basin. However, the river instead runs into the new obstacle of human development, which prevents the river from naturally redirecting itself.

closer to the ocean is typically where sandbars and **mudflats** form. These are thick, flat layers of mud or sand that are covered by water during high tide. The ocean edge of an estuary is usually always covered by water, although its depth changes with the tides. During high ocean tides, saltwater rushes into the estuary, bringing with it sediment, nutrients, and organisms from the ocean. Sometimes, the tide is so high that the ocean reaches many miles upstream into a river. In some rivers, such as the Severn in England and the Seine in France, incoming tides can send a wave of water 3 feet (1 m) high, or more, surging up the river. Such waves are called **tidal bores.** In China's Qiantang River estuary, the incoming tide funnels seawater up the river in a wave so fast that the locals call it the *Black Dragon*; this wave reaches heights of up to 30 feet (9 m).

Estuarine environments are among the most productive on earth, creating more **organic matter**—very fertile material made of particles of dead plants and animals—each year than similarly sized areas of forest, grassland, or agricultural land. Many different types of **habitats** are found in and around estuaries, including shallow open waters, freshwater and salt marshes, swamps, sandy beaches, mud and sand flats, rocky shores, mangrove forests, and sea grasses. Both estuaries and deltas play important environmental roles. They remove harmful chemicals that have been deposited in them by river pollution. These chemicals are absorbed by the sediments and become trapped as new sediments settle on top of them. Over time, bacteria break down some of these harmful substances. Estuaries originally form because of flooding that submerges the last few miles of a river valley—either because of a rise in sea level or because the land has dropped. Most of today's estuaries have been formed by the slowly rising sea level of the last 18,000 years.

Estuaries are examples of once-dry valleys that have since become flooded. There are other examples of flooded valleys, however. More than 10,000 years ago, huge glaciers carved out long, U-shaped valleys in areas such as Norway, Argentina, and Alaska. When Earth warmed, some of those glaciers melted and flooded these glacial valleys to form long, narrow stretches of water along the coast called **fjords.**

SEA-LEVEL CHANGE

As estuaries demonstrate, sea level does not always stay constant. Sea level at the shore can change over long periods of time. For example, many of the ancient Roman ports around the Mediterranean Sea, such as Caesarea on the coast of Israel, now lie underwater. At the time of the Roman Empire, the sea level of the Mediterranean was much lower than it is today. In contrast, on Romney Marshes, in Kent, England, the old seaport of Rye is now more than 2 miles (3 km) inland. During the last Ice Age, 18,000 years ago, the sea level was about 400 feet (122 m) lower than it is today. It was then possible to walk from England to France. Since that time, sea level has risen about 3 inches (8 cm) every 100 years. The sea level also has been higher than it is today. During the period when there were no ice sheets, sea levels were 340 feet (100 m) higher than present. Scientists predict that global warming will cause significant rises in sea level over the course of the twenty-first century. Since 1900, the sea level has risen 0.04 to 0.08 inches (1 to 2 millimeters) each year. In the last two decades, this rate has increased to about 0.12 inches (3 mm) per year. This may not sound like much of an increase, but it does add up. The oceans are, on average, about 6.3 inches (16 cm) higher now than they were in 1930. And as the sea level changes, so do coastlines. When the sea level increases, land disappears. The U.S. Environmental Protection Agency estimates that a 2-foot (0.61 m) rise in sea level would eliminate approximately 10,000 square miles (16,000 sq. km) of land in the United States alone—an area equal to Massachusetts and Delaware combined. And when land rises, or the sea level falls, old shorelines are sometimes left stranded. These shores form raised platforms called **raised beaches**, which lie above the new level of the sea.

More than 630 million people live in coastal areas within 30 feet (9.1 m) of sea level. Growing sea levels could cause difficulties for coastal communities in the next centuries, including such

Fjords such as the Geirangerfjord in Geiranger, Norway, were formed when retreating glaciers carved large, U-shaped valleys. The valleys then filled with water.

problems as coastal erosion and higher flooding. For example, many major cities such as London and New Orleans, which already need storm-surge defenses, would need to add more.

As sea levels rise, more areas require barriers to protect residents. In 1953, about 2,000 people in the Netherlands drowned when huge waves from the North Sea swept across the coastland. Half of the country lies below sea level. Since then, the country has built permanent sea walls. In some areas, these walls are massive: In the seaside village of Petten, for example, the sea wall stands 42 feet (13 m) high and is perhaps 50 yards (46 m) thick at its base.

THE SALT OF THE OCEAN

All water, even rainwater, contains dissolved chemicals that scientists call "salts." Not all water tastes salty, however. The saltiness of the sea comes from dissolved minerals, especially sodium, chlorine, sulfur, calcium, magnesium, and potassium. (Table salt is made of sodium and chlorine.)

If the salt in the sea were spread evenly over the Earth's land surface, it would form a layer more than 500 feet (166 m) thick, about the height of a 40-story building. The saltiness of the ocean is more understandable when compared with the salt content of a freshwater lake. For example, evaporating 7 gallons (28 L) of seawater yields about 2.2 pounds (1 kilogram) of salt. In contrast, 7 gallons (28 L) of freshwater from Lake Michigan contains only one one-hundredth of a pound (0.01 kg) of salt, or about one-sixth of an ounce (4.5 grams). Thus, seawater is 220 times saltier than the fresh lake water. The world's first oceans were probably only very slightly salty. As the Earth formed, gases spewed from its interior and released salts that reached the ocean via rainfall or land runoff. Some of the ocean's salts came from rocks and sediments that eroded. The oceans also contain dissolved gases from the atmosphere. As the ocean circulates, the waves and the pressure from the atmosphere push gases into the water. These gases include carbon dioxide, nitrogen, and oxygen. In lakes, relatively rapid turnover of water and its dissolved salts keeps the water fresh. For instance, a water droplet and its salts will stay in Lake Superior for less than 200 years, compared to roughly 100 to 200 million years in the ocean. Even when salt accumulates in a lake, it washes out quickly.

Ocean salts, on the other hand, have no place to go. Geologists believe that the saltiness of ocean water has been the same for at least a billion years. That does not mean, however, that all ocean water is equally saline. Salinity increases when an ocean evaporates or if parts of it freeze to form ice. It decreases with the addition of water from rainfall, runoff, or melting ice. The average salinity of seawater is 35 parts per thousand—or 35 pounds (16 kg) of salt per 1,000 pounds (454 kg) of seawater. In warm places such as the Red Sea and the Persian Gulf, where evaporation rates are high, water can have concentrations as high as 40 parts per thousand. Of the major oceans, the North Atlantic is the saltiest; its salinity averages about 37.9 parts per thousand. Salinities are lower than average in coastal waters,

Drowning Islands

As global temperatures continue to rise, the oceans will warm up and expand, ice caps and glaciers will melt, and more precipitation will fall as rain instead of snow. This will result in a rise in sea levels. Globally, sea levels have already risen four to ten inches (10 to 25 cm) in the last century. Researchers expect them to continue rising. For some coastal communities and small islands, rising waters are already making their mark. The tiny, sea-swept nation of Tuvalu, for example, is already in danger of sinking beneath the waves.

Tuvalu consists of nine low-lying islands totaling just 10 square miles (26 sq. km) in the Pacific Ocean. In the past few years, their coastlines have retreated; waves have washed over the islands' main roads; coconut trees stand partly submerged; and small patches of cropland have become unusable because of intruding saltwater. Like many South Pacific islands, there is little higher land to which people can move. Tuvalu's highest point rises less than 16 feet (5 m) above sea level.

The Tuvalu government, along with many experts, already assume the worst: Sometime in the next 50 years, if rising sea-level in the polar seas, and near the mouths of large rivers. Along the coastal areas of the United States, salinity varies with the month of the year as well as with location. For example, the ocean water off Miami Beach, Florida, varies from about 34.8 parts per thousand in October to 36.4 parts per thousand in May and June, when warmer temperatures increase evaporation of seawater. Across the country, off the coast of Astoria, Oregon, the salinity of seawater varies from 0.3 parts per thousand in April and May, when heavy rains and snowmelt feed rivers, to

predictions prove accurate, the entire 11,000-strong population will have to be evacuated. Fortunately, the New Zealand government has assured Tuvalu that it will accept the entire population if the worst happens.

Rising seawater is a constant threat in the tiny island nation of Tuvalu. Saltwater regularly floods the land, destroys homes, and prevents the citizens from farming.

2.6 parts per thousand in October. The water off the coast of Miami Beach has a high salt content because it is undiluted seawater. Off the coast of Astoria, however, the seawater is less

Drinking Seawater

Getting a clean and steady supply of freshwater can be a challenge, especially in many dry regions of the world. To meet these challenges, desalination plants have been built to convert seawater to drinking water. More than 7,500 desalination plants operate worldwide. Of these plants, 60% are located in the Middle East; the world's largest plant is located in Saudi Arabia. There are two ways to remove salts from seawater. The most common method is distillation, a process that takes its cue from nature. During the water cycle, the Sun causes water to evaporate from lakes, oceans, and streams. The water vapor eventually meets cooler air, where it recondenses to form dew or rain. Distillation imitates this process at a faster rate. First, large volumes of seawater are heated. The pure water, which evaporates and then condenses onto cold pipes, is collected. The salts and other minerals are left behind. In North America, the largest seawater desalination facility uses a different method, called **reverse osmosis**, to make drinking water from the saltwater in Florida's Tampa Bay. Seawater enters the plant and passes through screens that filter out shells, plants, and other material. Eventually, the reverse osmosis process begins. Under extremely high pressure, water is forced through a series of membranes, filters with pores about one-hundredth the width of a human hair. These holes are so small that only ultra-tiny molecules of water can pass through, leaving behind larger molecules of dissolved minerals such as salt. The Tampa Bay Seawater Desalination Plant produces up to 25 million gallons (95 million L) of desalinated drinking water each day.

salty because it is mixed with freshwater from the mighty Columbia River.

No matter where the meeting takes place, when a river mixes with the ocean, something always happens: sediments swirl, new land forms, water changes its chemistry. The partnership between oceans and rivers helps define how our coastlines, estuaries, deltas, and salt marshes shift, creep, sink, or grow.

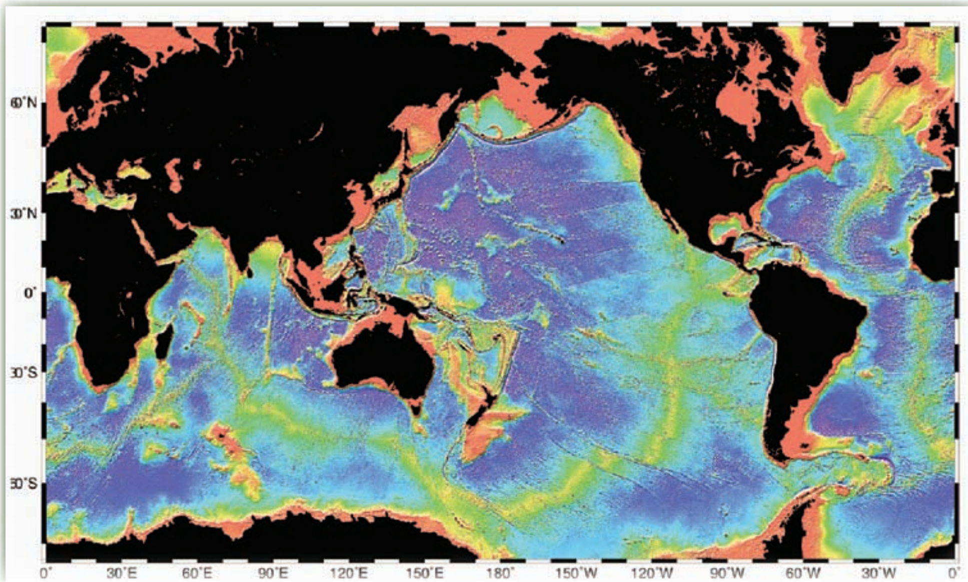
5

What Lies Beneath: THE RESTLESS OCEAN FLOOR

SALTWATER COVERS ALMOST 70% OF THE EARTH'S SURFACE. THE continents and islands divide all this water into five oceans: the Pacific, Atlantic, Indian, Southern (Antarctic), and Arctic oceans. Actually, however, these oceans are really one giant body of saltwater. Because they are all connected, changes in one ocean will eventually affect the others. The largest ocean, the Pacific, covers nearly one-third of the planet. At its widest point, between Panama and Malaysia, it stretches 11,000 miles (17,700 km)—nearly halfway around the world. The smallest of the five oceans, less than a tenth of the size of the Pacific, is the chilly Arctic Ocean.

In some places, the oceans are divided into different areas called seas. Some seas sit in the middle of an open ocean, such as the Sargasso Sea, which lies in the middle of the Atlantic Ocean. Other seas are partly enclosed by land, such as the Mediterranean Sea, which is also part of the Atlantic.

The oceans and seas did not always look as they do today. Like a jigsaw puzzle, the Earth's hard outer **crust** is split into seven large pieces and many small ones: These pieces are called **plates**. The plates float like giant rafts on the layer of softer rock beneath the crust. As these plates move, sometimes drifting apart,



A bathymetric map of Earth shows the features and varying depth of the ocean floor. The colors are computer generated to show changes in elevation.

sometimes colliding, they change the shape and the size of the world's oceans.

About 200 million years ago, all the continents formed one giant landmass called **Pangaea**. A single, vast ocean, called **Panthalassa**, surrounded it. When Pangaea spilt into today's continents, the Indian, Atlantic, Arctic, and Southern oceans were formed. Panthalassa slowly shrank until it became what is today's Pacific Ocean, an area about half the size Panthalassa once was.

The ocean floor also undergoes many changes. Unlike the flat bottom of a swimming pool, it has active volcanoes, steep valleys, large mountains, deep trenches, and wide-open plains—the same features that are found on dry land. In fact, some of those mountains dwarf even the Himalayas, some trenches would swallow the Grand Canyon whole, and a few of those vast plains easily rival Africa's Sahara Desert in size.

Pangaea

About 250 million years ago, the continents as we know them were all part of one massive supercontinent called Pangaea.

OCEAN MAPPING

Scientists divide the ocean into different zones, depending on the depth of the water. Until recently, however, scientists did not really know what the deep ocean bottom looked like. In the 1800s, oceanographers took water-depth measurements with weighted ropes and chains by lowering the rope from the side of a ship into the water until it hit the seafloor. Then they would measure the length of the rope to calculate ocean depth. This method is not very precise, however, and was only good for measuring the depth of coastal waters, which are shallower.

Studying features of the ocean that lie far below the surface is not a simple task. For one, the deep-sea bottom is difficult to reach. The normal depth limit for a scuba diver, equipped with a tank for breathing air, is about 164 feet (50 m), yet most of the seafloor lies much deeper than that. The greatest challenge of deep-sea exploration is overcoming extreme pressure: The deeper underwater you go, the greater the pressure, which is the weight

Ice in the Ocean Floor

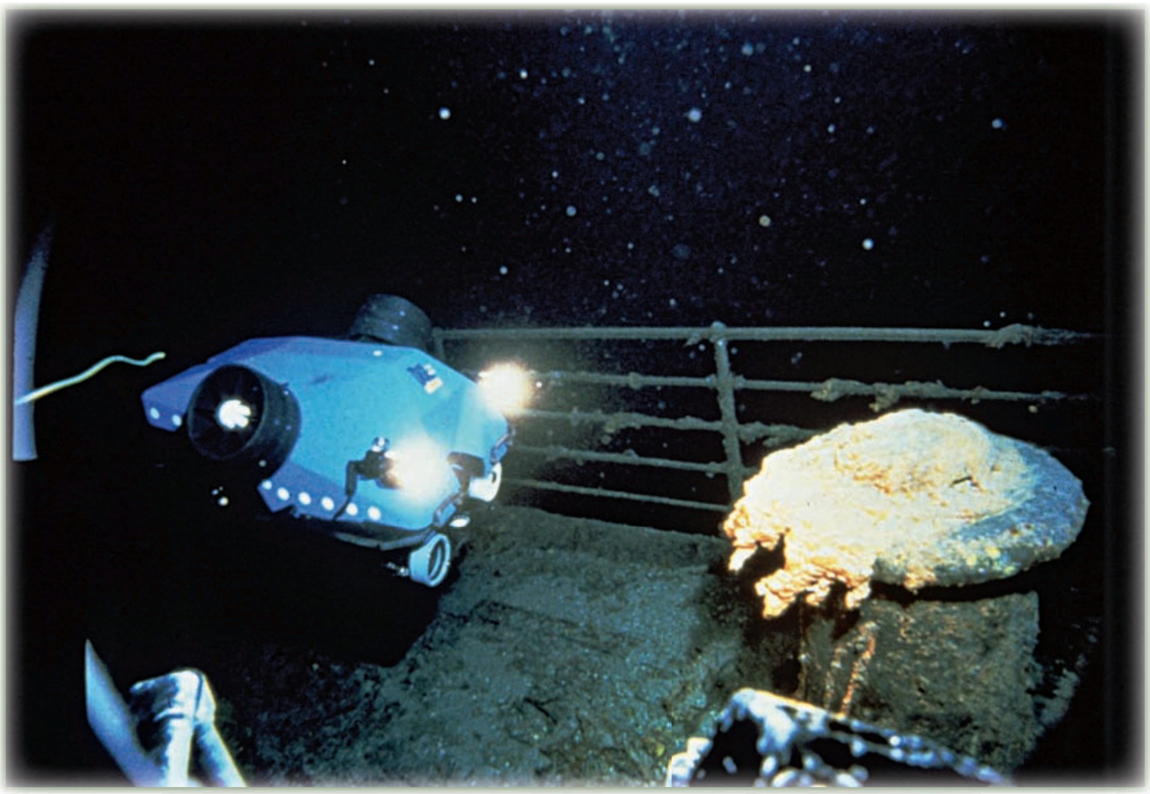
Hidden below the ocean floor is an ice-like substance. Some scientists believe it could solve the world's energy problems. Others worry it could catastrophically change our climate. At very low temperatures and high pressures, some gases can combine with water to form a crystal-like substance resembling ice, called a gas hydrate. These gas hydrates look like hard-packed snowballs. Since the 1960s, researchers have been discovering vast amounts of methane-gas hydrates in deep-ocean sediments. According to the U.S. Geologic Survey, 100,000 to 300 million trillion cubic feet (2,800 to 8.5 million trillion cubic m) of methane exists in hydrate form—most of it in the ocean floor. The seafloor off the coasts of North Carolina and South Carolina holds huge deposits.

For now, these deposits are tucked safely in the ocean sediment, but if the methane-hydrates were brought to the surface, the ice would "melt" and the gas would escape into the atmosphere. The consequences could be dire, because methane is a greenhouse gas that is 21 times more effective at trapping heat than carbon dioxide. Today, 3,000 times more methane exists in hydrate deposits than in the atmosphere. Releasing even a fraction of this amount would cause the global climate to warm up.

On the other hand, gas hydrates offer a potentially enormous energy supply—more than all of the oil, gas, and coal we are currently able to access. For this reason, many scientists are studying ways people might be able to harness this energy safely.

of the water above you. At a depth of 30,000 feet (9,100 m), the pressure is similar to the weight of an elephant balanced on a postage stamp.

Today, by using special vehicles and equipment, scientists can reach all but the very deepest spots of the ocean floor. Special pressurized suits for divers have been designed that work like wearable submarines. The pressure inside the tough, hard-shelled suit keeps the same normal pressure that divers experience on the surface of the ocean. By wearing these special suits, divers can go as deep as 1,640 feet (500 m). In 1960,



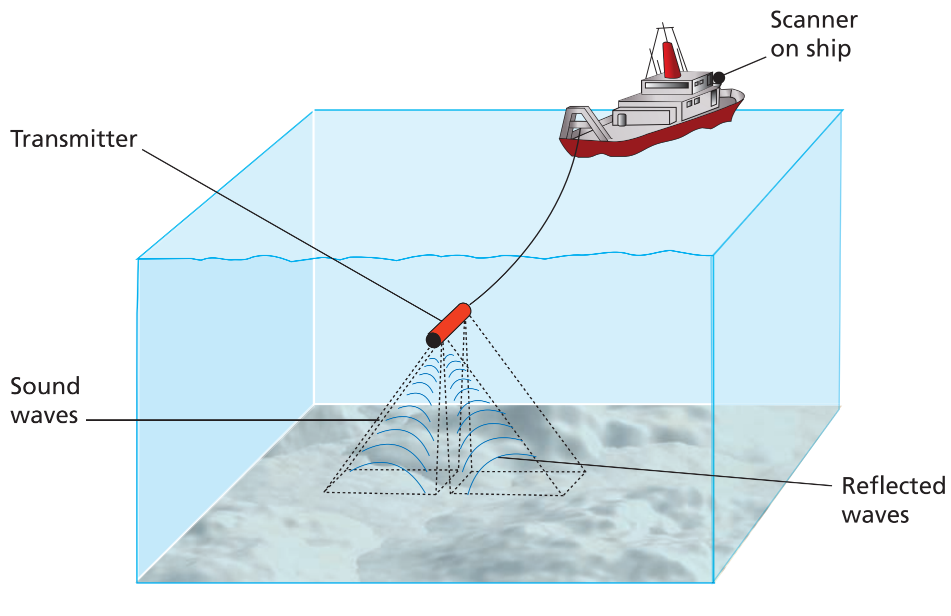
Alvin, a submersible capable of carrying humans to crushing depths of the ocean, explores the famous wreck of the RMS *Titanic* on the floor of the Atlantic Ocean.

the bathyscaphe *Trieste*, a type of submarine, dived 35,813 feet (10,916 m) to the bottom of the Mariana Trench in the Pacific Ocean, a descent that took nearly five hours. The crew traveled in a steel ball protected by walls nearly 5 inches (13 cm) thick to keep them from being crushed by the huge pressure present on the ocean floor. Submersibles are another type of underwater vehicle. One of the most widely-traveled is *Alvin*, a vehicle that has made more than 4,200 dives. It is able to reach nearly 63% of the ocean floor. The sub's most famous exploits include exploring the first known **hydrothermal vents** in the 1970s and surveying the wreck of RMS *Titanic* in 1986.

Alvin is capable of carrying two scientists and a pilot to a depth of about 14,700 feet (4,500 m), or almost 3 miles (4.5 km). Each dive lasts 6 to 10 hours. *Alvin* can hover, maneuver in rugged topography, and rest on the seafloor. The sub is equipped with various video cameras. Because no sunlight reaches the deep sea, the submersible must carry its own lights. *Alvin* has two robotic arms that can manipulate instruments, and its basket can carry up to 1,500 pounds (680 kg) of tools and seafloor samples. Another submersible, the Russian *Mir 1,* can journey down to 20,000 feet (6,100 m).

Some parts of the ocean are too deep or too dangerous for people to reach. In those cases, scientists use remotely operated vehicles (ROVs) to film, measure, and collect samples. ROVs can stay underwater much longer than people, sometimes for months at a time. Long cables connect them to a main ship. Cameras on the ROV transmit images to operators on the ship, who steer the vehicle by remote control as if they themselves were actually inside it. Shipboard instruments can also reveal important information about the ocean. Researchers use sound to measure ocean depth by using a **sonar** device that sends pulses of sound down to the ocean floor. By measuring how long it takes for the sound to echo back to the surface, they can calculate the depth of the seafloor. The longer the sound takes to bounce back up, the deeper the seafloor is. Sonar, which stands for **so**und **na**vigational **ra**nging, has been in use since

Sonar Techniques



Sonar uses sound waves to measure the depth of the ocean floor. The distance to the seafloor is measured by the time it takes for a sound to travel to and from the sound transmitter.

the 1920s. In recent years, it has become much more advanced. Working together with satellites in space, modern sonar can reveal even tiny features of the ocean floor. GLORIA, one of the most widely used satellite sonar systems, is able to map wide bands of seafloor, rather than just getting depth from one spot. GLORIA can cover 7,700 square miles (20,000 sq. km) in a single day. The maps made from GLORIA's records are extremely detailed. Such maps, which show the different depths of the seafloor, are called **bathymetric maps**.

Satellites, such as SEASAT, measure the distance between themselves and the surface of the sea. Peaks and valleys on the surface correspond to those found on the sea floor. For example, the surface of the sea can be dozens of feet higher over oceanic mountains than over valleys or plains. Satellites can also take other measurements of the ocean's surface, such as temperature.

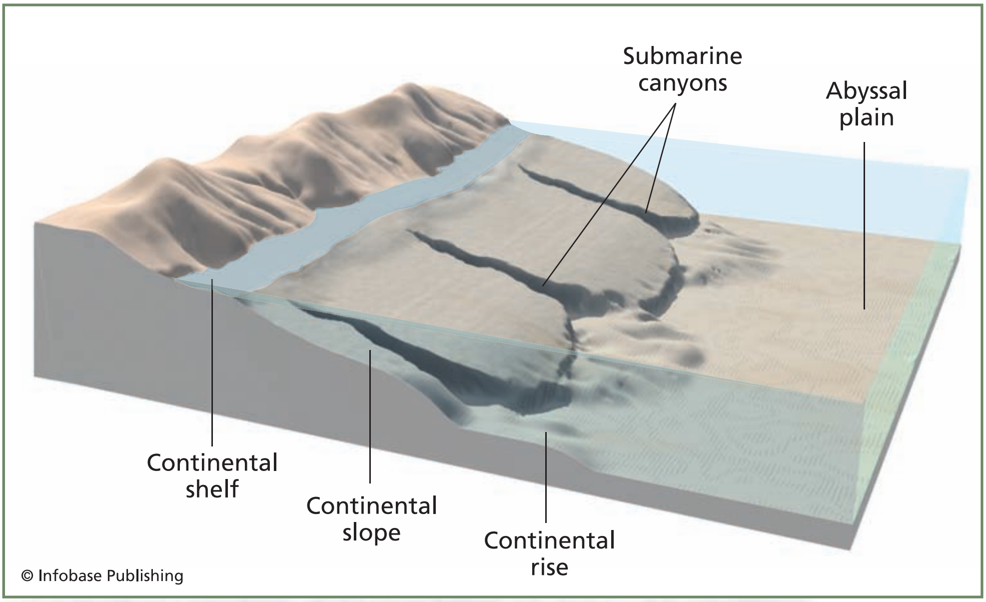
UNDERSEA LANDSCAPE

The ocean begins, of course, at the shore, the boundary where the surface of a continent descends first to sea level and then beneath it. From the edges of the continents, the land slopes gently downward. The sea is not very deep here, typically only up to 443 feet (135 m). This shallow ledge of ocean floor is called the **continental shelf.** It borders every continent. Some shelves, such as the east coasts of North and South America, are very wide. Others, such as the west coasts of North and South America, are quite narrow. The average width of a continental shelf is 43 miles (70 km). The continental shelf ends at a sudden drop-off called the shelf break. Most of the fish that people eat are harvested from the waters over the continental shelves. Beyond the shelf break, the ocean floor's slope becomes much steeper. This sharp descent is called the **continental slope.** It is about 10 miles (16 km) wide, on average, and drops to a depth of about 1.5 miles (2.4 km). After that, it begins to flatten out. This gentle sloping zone, which may be several hundred miles wide, is called the **continental rise**. It is made by the build-up of fine-grained sediments such as silt and clay that have been washed into the ocean from land, usually by rivers. In fact, the continental slope and rise are both vast dumping grounds for thick deposits of sediments carried from the land. Rivers carry billions of tons of sediment into the sea every year. Huge canyons and gullies cut down along the continental slope. These are formed by underwater landslides called **turbidity currents**, which rush violently down the slope at speeds as fast as 50 miles (80 km) per hour. Much like a mudslide on land, these swift slurries—or "rivers of mud"—carry large masses of sediment down the slope, leaving behind gaping canyons and gullies. The **abyssal plain**, the flattest part of the ocean, begins where the continental rise ends, at a depth of about

2.5 miles (4 km). These vast, flat stretches of land cover nearly half the seafloor and, combined, are nearly equal to all the area of the Earth's land. They are made up of solid rock covered with a layer of sand, gravel, clay, silt, and ooze—the remains of billions of sea creatures collected over many years. On average, the layer is 100 feet (30 m) thick. The thickness can vary greatly, however. The floor of the Mediterranean Sea, for example, has a layer 6,500 feet (2,000 m) thick.

Like giant pancakes, abyssal plains make up some of the flattest landscapes in the world. The one off the coast of Argentina, for example, changes less than 10 feet (3 m) in elevation over a distance of 800 miles (1,287 km).

Every ocean has mountains. Abyssal plains are dotted with thousands of small, extinct volcanoes called **abyssal hills**. The abyssal plains of the Atlantic Ocean are smooth because its abyssal hills are buried under a thick blanket of silt and clay that has been deposited there by runoff from rivers. In contrast, there are tens of thousands of unburied abyssal hills in the Pacific Ocean, which is ringed by deep trenches along its edges. These trenches trap sediment that flows from land before it can spread out over the ocean floor. Abyssal hills that rise more than 0.6 miles (1 km) high are called **seamounts.** Some seamounts, called **guyots**, have flat tops that were created over thousands of years by waves that wore away their tops. Most guyots are the remains of drowned volcanic islands that sank beneath the waves long ago. In general, most seamounts occur in groups or chains. Some seamounts are so huge that they poke above the ocean surface to become islands. The Hawaiian Islands are one example of a chain of seamounts that grew above the ocean's surface. Hawaii's volcanoes were created by a stationary heat source that lies deep in Earth's interior, called a hot spot. Like a blowtorch melting holes in a sheet of metal, the hot spot has burned holes in the crust of ocean floor above it. At this time, a hot spot lies under the Big Island of Hawaii, supplying hot, liquid lava to its three active volcanoes, the tallest of which is Mauna Loa. When measured from its base on the seafloor, Mauna Loa is the



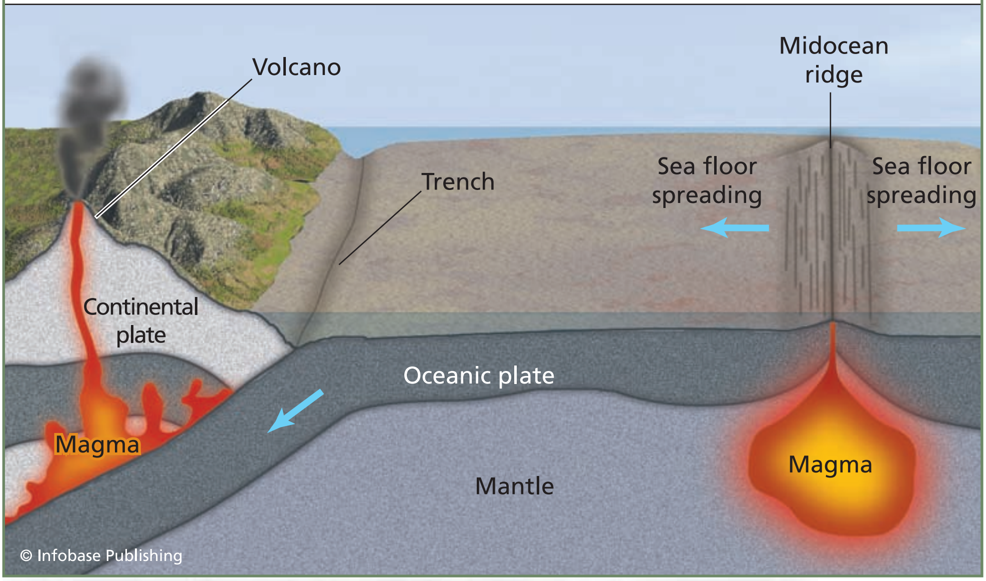
The continental shelf begins to slope downwards at the continental slope, where it eventually meets the continental rise. Beyond the continental rise, the abyssal plain extends outward.

world's tallest and most massive mountain, towering more than 30,000 feet (10,000 m) high from base to summit. Mauna Loa's base covers an area about the size of Connecticut.

A fourth active volcano, Loihi, is currently erupting on the seafloor just south of the Big Island. In the future—roughly 50,000 years from now—the seafloor's movement will carry the Big Island away from the hot spot. As a result, its volcanoes will become inactive, and a new island will form as Loihi's eruptions continue to build its peak. This new island will then be the youngest member of the Hawaiian Island Chain. And one day—many, many thousands of years from now—some of the existing Hawaiian Islands will become guyots. Sometimes seamounts become islands much faster. On November 15, 1963, the island of Surtsey suddenly erupted from the sea south of Iceland. Within a few days, the new island was 197 feet (60 m) above sea level and more than 0.3 miles (0.5 km) long.

At some point beyond the abyssal plain, which may be several hundred miles wide, the ocean floor begins to rise again in a gentle slope. At mid-ocean, the rising floor meets a long, volcanic mountain chain that usually extends down the middle of the ocean. This is called the **mid-ocean ridge**. The ocean ridges form a great mountain range, almost 40,000 miles (64,000 km) long, that weaves its way through all the major oceans. It is the single largest feature on Earth. The Mid-Atlantic Ridge, for example, snakes down the middle of the Atlantic Ocean from the North Pole to Antarctica. As the ocean floor climbs slowly toward the center of the mid-ocean ridge, its blanket of sediment gets thinner. The ocean floor is further marked by thousand-mile cracks called **fracture zones** that lie at right angles across the mid-ocean ridge. Along the center of the mid-ocean ridge is the **rift valley**, a deep, V-shaped notch. From this valley, molten lava constantly erupts and cools to form new seafloor. The rocks that make up the ocean floor here are mostly made of **basalt**, a hard, black volcanic rock. Twin sheets of fresh crust emerge along each side of the rift valley and flow slowly away from it in opposite directions. The reason for all of this activity is major movement: Earth's plates are spreading apart along the mid-ocean ridge. At the Mid-Atlantic Rift Valley, one sheet of crust flows east and the other flows west at a rate of about 0.5 inches (1.3 cm) per year. The older, more distant parts of these growing sheets of crust are gradually covered by sediments and eventually become the abyssal plains and continental rises. Moving at about the speed that fingernails grow, these spreading sheets of ocean floor push the land on each side of the Atlantic Ocean farther apart, a process called **seafloor spreading**. A million years from now, the Atlantic Ocean will be about 25 miles (40 km) wider than it is today. In fact, this ocean—the planet's youngest—was only born about 130 million years ago, when the continents that formed from the breakup of the ancestral mega continent, Pangaea, were being rifted apart by the process of seafloor spreading. For the past 30 million years, a similar process has been slowly separating

Plate Tectonics Model



A mid-ocean ridge forms where two tectonic plates move apart. Magma welling up under a ridge causes new seafloor to form and spread. Trenches form in a subduction zone, where an oceanic plate plunges under a continental plate.

the African and Arabian plates to form the Red Sea. This offers a modern-day example of what the Atlantic Ocean might have looked like in its early years. The Red Sea is currently about 220 miles (350 km) at its widest point, but it is growing. Magma bubbling up through the Red Sea floor is pushing the Arabian plate and the African plate apart. If the widening continues at its current rate, in 200 million years the Red Sea will be as wide as the Atlantic is today.

Just as there are spots on the ocean floor where new crust is forming, there are also areas in the ocean where old crust is disappearing. Called **subduction zones**, or deep-sea trenches, they are the deepest places in the ocean. At these trenches, the moving seafloor is recycled into Earth's interior. They run mostly along the western, northern, and eastern edges of the Pacific Ocean and range from 4 to 6.8 miles (7 to 11 km) deep. Along these areas, a sheet of old oceanic crust becomes squeezed under continental crust and disappears, diving deep into the Earth—which is why the Pacific Ocean is getting a little bit smaller every year. Of the 20 major deep-sea trenches in the world, 17 of them are located in the Pacific Ocean. The deepest is the Mariana Trench, near the island of Guam in the western Pacific Ocean. It is deeper than Mount Everest, the highest mountain on land, is tall: Mount Everest, measured at 29,035 feet (8,850 m), could sink in that spot and still disappear beneath the surface. The trench has a maximum recorded depth of 36,198 feet (11,033 m). Chains of

Mining the Ocean Floor

The world's hunger for valuable minerals such as copper and iron is drawing some explorers to search the deep-ocean floor. One possible source is manganese nodules. Scattered like potatoes in a field, these nodules cover many parts of the ocean floor and range in size from microscopic pebbles to potato-sized stones. They are rich sources of several minerals and metals. Built of onionlike layers of manganese and iron oxides, nodules lie partially or completely buried in the seabed sediment. They also contain copper, nickel, and cobalt. The steady rain of plant and animal remains falling into the deep sea provides metals to nodules. However, nodule growth is one of the slowest of all Earth's building processes—on the order of a half an inch (one cm) over several million years. These blackish-brown lumps can be found at any depth, but they usually grow on the vast abyssal plains in the deep ocean at between 13,000 and 20,000 feet (4,000 and 6,000 m). The biggest concentrations appear to lie in the north central Pacific Ocean, the Peru Basin in the southeast Pacific, and the center of the northern Indian Ocean.

large volcanoes form the outer edges of deep-sea trenches. The Andes Mountains of South America and the islands of Japan are both examples. Friction between rocks during subduction also causes powerful earthquakes. The geologically active subduction zones that surround the Pacific Ocean are often called the "Ring of Fire."

There are other places in the ocean that can get a little hot and steamy. In 1996, while drilling for minerals on the ocean floor, scientists aboard a research vessel were shocked to find fountains of super-hot water bursting through the holes they were drilling. Temperatures were more than 550°F (288°C). It turns out that the scientists had discovered a system of hydrothermal vents, natural hot springs gushing through the seafloor at a depth of 1.7 miles (2.7 km) below the surface. Hot springs such as these occur elsewhere on the seafloor, and also on land—in Yellowstone National Park, for instance, where water that has seeped into the ground comes into contact with volcanic heat, forcing the water to erupt into the air in what is known as a *geyser*. Deep-ocean vents spew out water rich in many minerals such as iron, lead, and copper. These minerals sometimes color the water so that some vents are called "black smokers" or "white smokers." When the hot water cools, the minerals dissolve out. As they fall to the ocean floor, they build up layer upon layer to eventually form chimneys. Over time, these towers can grow 50 to 65 feet (15 to 20 m) high. Strange, never-before-seen creatures—such as giant clams the size of dinner plates and tube worms that grow up to 12 feet (3.7 m)—live around these vents, which serve as a warm oasis in an otherwise cold and dark world.

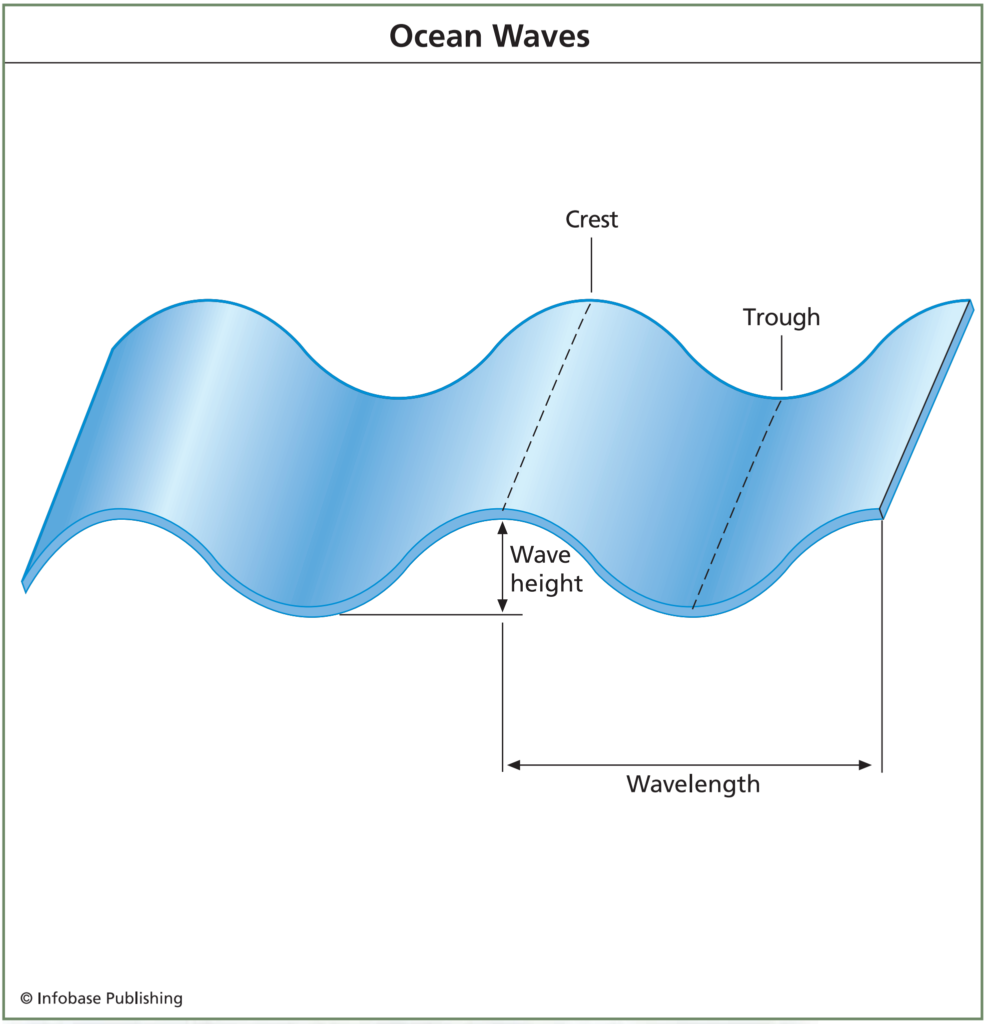
6

The Ocean in Motion: THE POWER OF WAVES AND CURRENTS

IF ALL THE WORLD'S COASTLINES WERE PULLED INTO A STRAIGHT LINE, they would circle the equator almost 13 times. The total amount of coastline in the world, not counting small bays and inlets, is 313,186 miles (504,000 km). This amount changes, however, because coastlines are always changing thanks to the force of ocean waves: Waves pound against the shores and fling up boulders, pebbles, and sand. They carve out bays and caves, cut steep cliffs, build peninsulas, and form long spits of sand called **barrier islands**. Waves can act like a huge saw, cutting away the softer rock at the foot of a cliff until part of the cliff collapses. For example, the lighthouse on the coast at Martha's Vineyard, Massachusetts, has had to be moved three times in its history. Every year, the waves wear away about 5.5 feet (1.7 m) of the cliff on which it stands.

FROM WIND TO WAVES

Most ocean waves are created by the wind. Picture the ocean as a calm, flat surface. As winds blow over the water, they create tiny wavelets, just like the ripples that streak across your soup when



An ocean wave is made up of two main parts. The crest marks the top of a wave, and the trough is the lowest point between two crests. The distance between two crests is called the wavelength.

you blow on it to make it cool enough to eat. The wavelets move in the same general direction as the wind, and, if the wind is strong enough, they will form into stable waves that travel along with the wind.

Although a wave moves across the ocean, the actual ocean water does not. Each particle of water traces vertical circles within the wave, with each particle returning after a circuit around the circle to its original location in the ocean. Basically, ocean waves are traveling fluctuations in water level—that's why boats bob up and down in the open ocean in one spot.

The distance over which an ocean wind affects a train of waves is called the **fetch.** The longer the fetch, the longer and faster the waves. And the stronger the wind, the larger the waves it creates. Giant waves towering to 60 feet (18 m) that crash on the shores of Europe sometimes originate off the coast of the United States, some 2,000 miles (3,219 km) away. The long fetch speeds these waves along, stretches them out, and builds them up to impressive heights.

A wave is made up of different parts. The top of a wave is called the **wave crest**; the lowest point between two wave crests is called the **wave trough**; and the distance between two wave crests is the **wavelength**. The length of time it takes two successive wave crests to pass some fixed point (such as a rock) is known as the **wave period.** Waves that travel across the open ocean are called **swells**. The average height of an ocean wave is about 12 feet; but far larger waves—50 feet or higher—are sometimes born during raging storms in the open sea, particularly in the northern Atlantic and in the Southern Ocean. These waves, called **rogue waves**, form when storm waves stack together to form powerful walls of water in the open sea. Such massive waves have claimed many ships. Eventually, waves roll ashore. As individual swells enter shallower water, the bottom portion of each wave begins to slow down as it drags along the ocean floor. At the same time, the upper portion of the wave continues to move at its original speed. As a result, waves compress. The slowing waves squeeze together and become steeper and taller. Eventually, the top of a wave outruns the bottom of the wave, causing the wave to break and unleash the energy it has been carrying. Breaking waves crash on to the beach to form **surf**—the white froth made as air mixes into the water.

The steeper the slope of the beach, the higher the waves tend to crest. This is one of the reasons why California beaches are better for surfing than beaches on the East Coast of the United States. On the West Coast of the United States, the continental shelf is narrower and the continental slope is steeper. There, the ocean floor drops off like a cliff. On the U.S. East Coast, the shelf is broader; it drops gradually, like a really long ramp. Near the surface of the ocean, water particles are spinning in the direction of the wind's movement. As the wave moves inland and hits the upward slope of the continental shelf on the East

Surfing Jaws

Big waves are a surfer's dream. The most dangerous and challenging wave system in the world is called "Jaws." It explodes along the edge of a hidden offshore ridge near Maui, Hawaii. A few times each year, storm swells originating as far away as Alaska's Aleutian Islands make their way to this Maui surf spot. There, a volcanic reef that lies just over a half-mile (0.8 km) offshore sculpts the swells into 40- to 70-foot (12- to 21-m) walls of water.

The reef acts like a giant magnifying lens, bending and enlarging Pacific Ocean storm swells to monster surfing waves that race up to 30 miles (48.3 km) per hour. At the Jaws site, the ocean depth changes abruptly from 120 feet (37 m) to just 30 feet (9 m), as waves move from deep sea to the beach. Normal-sized waves do not react to the ridge because they do not reach far enough down to meet it. Storm swells longer than about 1,000 feet (305 m) in length, however, literally trip over the ridge. Surfers say that surfing Jaws feels like jumping off a cliff. The total surf time lasts nearly a minute—an eternity compared to the typical 5- to 30-second rides experienced while riding smaller waves.

Coast, the friction causes the particles to slow down, so the wave is smaller and breaks farther out from shore. On the West Coast, the shelf rises suddenly near the coast, so the waves are much larger when they crash into the coastline. The particles (and thus the wave) have not been slowed down by extended friction with the shelf.

THE CHANGING SHORE

The energy released by waves can move sediment onshore, offshore, or parallel to the shoreline. For example, a breaking storm wave hurling thousands of tons of water at the coastline also brings rocks and can break apart the protective concrete walls built along some harbors. Where ocean shores are not made of hard rock, breaking waves can rapidly wear away the land. In certain areas of Britain, for instance, waves have eaten away several miles of the shore since Roman times. Over time, waves tend to straighten out a coastline as they wear away points that extend into the ocean and deposit sediment into bays. Eroding coasts are typically made of soft rocks, such as limestone. In contrast, hard rocks such as granite do not wear away as easily. Rocky outcrops that stick out from the coast, called **headlands**, are usually made of hard rock. Bays, which are carved into the coast, are made up of softer rocks that are more vulnerable to the forces of waves. Waves commonly carve out sea caves in places where the rock is soft and the waves are especially heavy and relentless. Sea caves are formed by hundreds or thousands of years of wave action that breaks away weak and loose pieces of rock. The pounding water also carries sand and gravel that chip away at the rock like millions of tiny hammers. The Pacific Coast of the United States has many sea caves. (One of the most famous is Sea Lion Cave in Oregon.) The constant push and powerful compression of water and air sometimes even punch a hole through the roof of a cave, actually blowing it right off to create what is appropriately known as a **blowhole**. Sometimes caves that grow on either side of a headland may eventually meet to form an arch. Continued

Sea caves such as Sea Lion Cave in Oregon are formed by the constant transforming power of ocean waves. Sea Lion Cave is the largest year-round home to the endangered Steller Sea Lion.

battering by waves may then break the arch to leave freestanding towers or stacks of rock.

As waves break on shore, a churning froth of water, called **swash**, moves as a sheet up the slope of the beach. Once swash runs out of energy, it flows back toward the surf zone as **backwash**. Depending on the strength of the surf, swash can scour sand, pebbles, and even rocks off the surface of the beach, while backwash deposits the debris back onto the beach, usually in a slightly different location.

This photo taken from space above the Provincetown Spit in Cape Cod shows the curved shape that often forms when waves push sand and other sediment that has washed to sea back toward shore.

When waves—particularly steep waves—hit a beach at an angle, they carry water along the beach along with sand and gravel. The water flows parallel to the shore in the form of a **longshore current**. These currents, hauling vast amounts of sand and gravel, can destroy beaches in some spots and create new ones in others.

Longshore currents off Sandy Hook, New Jersey, for example, move an average of 750,000 tons of sand per year along the shore. At Sandy Hook, the longshore current approaches from the south, carrying sand northward from the neighboring beaches. Sandy Hook is at the north end of the 127-mile (204 km) long New Jersey seashore. The narrow Sandy Hook peninsula, like other barrier beaches, islands, and sand spits along the New Jersey coastline, serves as a thin, fragile buffer between the mainland and the Atlantic Ocean. Over thousands of years, the longshore current created Sandy Hook, which probably began as a small sand bar. As the longshore current transported sand to the north end of Sandy Hook, it made the tip area curve or "hook" toward the northwest. One way to measure the changes to the tip of Sandy Hook is to consider the Sandy Hook Lighthouse. When completed in 1764, the Sandy Hook lighthouse was 500 feet (152 m) from the tip of the Hook. By 1864, the lighthouse was more than

Beach Sand

A lot of hard work went into making the beach sand upon which thousands of vacationers relax every year. Sand is made up of particles of worn-down rock that are washed down to the sea by rivers or created by waves that batter and grind down rocky cliffs. A few beaches contain some desert sand, such as those located on the Mediterranean Sea, where sand from the Sahara Desert blows in with the wind. Some beaches have sand made up of one color, such as the black lava beaches in Tahiti. Other beaches are a mixture of colors, made from different types of rock or from worn-down coral or seashells. White sand beaches, for example, are generally made of coral, seashells, and quartz. Grey beaches are mostly feldspar and granite.

3/4 of a mile (1.2 km) from the tip, and today the lighthouse is about 1½ miles (2.4 km) from the tip.

When a coastline curves or changes direction, longshore currents may wash sand and pebbles out to sea, forming a ridge called a **spit**. Because waves push them back to the coast, spits often have a curved shape.

TSUNAMIS

The tsunami is the most destructive kind of wave. The word comes from the Japanese words for *harbor* and *wave*. It refers to how these waves wash over an entire harbor. Japan seems to experience these fierce waves more often than other countries. Tsunamis can appear in any ocean, but they are more common in the Pacific Ocean's Ring of Fire. This ring, circling much of the Pacific, marks an area of great instability in Earth's crust. Tsunamis are triggered by undersea earthquakes or volcanoes. When the ocean floor moves up and down, it transfers huge amounts of energy to the water. At first, a young tsunami out at sea looks like a mere mound of water at the surface of the ocean that often passes unnoticed by ships. In the open ocean, the rippling waves—from crest to trough—can be less than 20 inches (0.5 m) high. That appearance is deceptive, however: The underwater wave movement can sometimes reach all the way down to the ocean floor. Tsunamis are also very long, stretching more than 124 miles (200 km) in length from crest to crest. They move fast, like a jet airplane, and can reach speeds of more than 500 miles (800 km) per hour. Tsunamis do not exert their destructive force until they reach the coastline. As they reach land, the waves slow down because they drag along the bottom. The back of the wave, however, may still be many miles behind in deep water—quietly speeding along. This slowing down causes the water to pile up behind, not unlike what happens when a car breaks down on a crowded highway and traffic builds up; except, in this case, the water cannot stop and has nowhere to go but up. The tsunami rears up—sometimes as high as 200 feet (60 m)—and slams down on the shore, rushing far inland. These waves have caused terrible damage to coastal areas, killing people and destroying buildings. The moments just before a tsunami strikes land can be eerie and calm. In some instances, when a trough hits land first, water is sucked out of harbors and bays. The temptation to explore the exposed ocean floor can be deadly. Such was the case when a group of curious onlookers walked onto the emptied shores of Hilo, Hawaii, in 1946, just before a tsunami struck. One of the biggest tsunamis in history took place on October 6, 1737. This one flooded the coast of Cape Lopatka, on the southern tip of the Kamchatka Peninsula in the far east of Russia. By the time the wave reached the shore, it towered 210 feet (64 m) into the sky. One of the deadliest tsunamis ever recorded happened more recently. On December 26, 2004, a 9.2 magnitude undersea earthquake shook the waters of the Indian Ocean. Within hours of the earthquake, the coasts of Indonesia, India, Sri Lanka, Thailand, and other countries were deluged with waves, some as high as 49 feet (15 m). More than 230,000 people died. To put that number in perspective, the second-deadliest tsunami was in Krakatau, Indonesia, in 1883. That tsunami killed more than 36,000 people. The Pacific Tsunami Warning Center collects information from more than two dozen countries. It keeps watch 24 hours a day for any suspicious shaking that might trigger a tsunami. On December 26, 2004, scientists knew within minutes that a massive earthquake took place off the island of Sumatra. The Pacific Tsunami Warning Center immediately issued a bulletin to nations in the Pacific, but they had no way to know it generated a tsunami. Despite a lag of up to several hours between the earthquake and the impact of the tsunami, nearly all of the victims were taken completely by surprise. There were no tsunami warning systems in the Indian Ocean to detect tsunamis. In the aftermath of the disaster, the United Nations has started to work on an Indian Ocean Tsunami Warning System.

OCEAN TIDES

The most obvious daily, visible change in the oceans is the regular coming and going—or ebb and flow—of the tides, the twice-a-day

The tidal range in the Bay of Fundy is one of the widest in the world. The differences in high and low tide are so great that some ships are left on dry land during low tide.

changes in the height of the ocean surface. At high tide the sea level rises; at low tide, it falls.

Tides are caused by the gravitational tug on the world's oceans by the Moon and the Sun, which act much like giant water magnets. On the side of the Earth turned toward the Moon, the Moon's gravity pulls the waters toward it, creating a **tidal bulge**. As Earth and its water are pulled towards the Moon, the water on the opposite side of the Earth naturally attempts to remain stationary due to *inertia*—the tendency of a body to remain at rest—resulting in a tidal bulge on the far side of the planet, as well. As the Earth rotates, the tidal bumps stay tracked on the Moon. Most shorelines experience two high tides and two low tides per day. It takes a little more than six hours for the rising waters to reach high tide. It takes another six hours for the falling waters to hit low tide. Although the Sun is 27 million times bigger than the Moon, it has less of an effect on the tides because it is much farther away. Nevertheless, the Sun does play a role on Earth's tides under special circumstances. When the Sun, Moon, and Earth are lined up, which happens twice a month, the Sun's tide-raising powers are added to that of the Moon, causing especially high tides that are called **spring tides**. When the Sun and Moon are at right angles to the Earth, however, the gravitational attraction of the Sun and Moon work against each other and cause small tides known as **neap tides.** Depending on the shoreline, tides can act quite differently. In some places, such as the Mediterranean Ocean, the difference between the high tide and low tide—known as the **tidal range**—is only about 3.3 feet (1 m) and the tide does not go out very far. In other parts of the world, however, the combination of tides with the shape of the coastline leads to huge tidal fluctuations, especially in areas where tidal waters are funneled into a bay or estuary. The greatest tidal range occurs in Canada's Bay of Fundy, in the Atlantic, where the difference between low and high tides can be up to 52 feet (16 m). During low tide, a huge swath of the seafloor is exposed, leaving boats high and dry.

Tides such as these carry extraordinary energy, and for ages people have been coming up with ways to tap into it. As far back as the twelfth century, people used tide-driven water wheels to provide power for sawmills and gristmills. More recently, power plants have been constructed in areas with large tidal variations. One of these, built at the mouth of the Rance River in France, makes use of strong tidal currents to drive turbines and generators. When strong tidal currents meet and clash, dangerous **whirlpools** sometimes form. This usually happens in areas where water flows through narrow passages between islands or landforms. For example, water roars so quickly through the Saltstraumen Channel, off Norway's northwestern coast, that the noise of the resulting whirlpools can be heard several miles away.

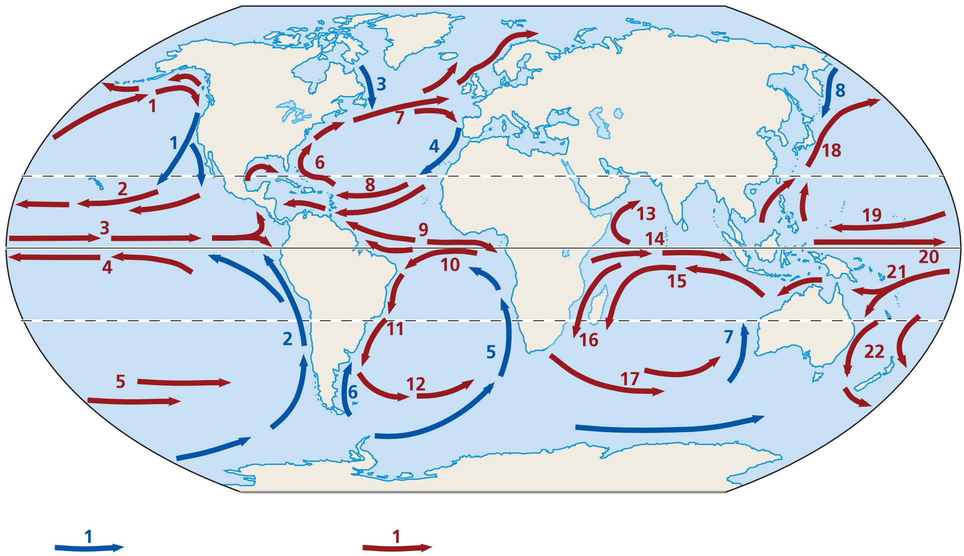
CURRENTS

Ocean currents are rivers of water that flow either on or near the surface of the ocean or deep underwater. The differences in the densities of seawater, caused by differences in salinity and in temperature, are the main initiators of deep-water currents: The warmer that water becomes, the lighter, or less dense, it becomes. Cold water, on the other hand, is heavier, so it sinks. When cold water sinks, warmer water rises to fill its place, thus setting a deep-water current in motion. The combination of wind and the spin of the Earth create surface currents.

The Plastic Duck Flotilla

Since 1992, oceanographers have been tracing the journey of some 30,000 plastic bath toys that were accidentally released into the Pacific Ocean when they were washed off a cargo ship. These ducks have been providing some fascinating information about ocean currents. The ducks began their life in a Chinese factory and were being shipped to the United States from Hong Kong when three containers full of ducks fell into the Pacific during a storm in January 1992. Two-thirds of the ducks floated south through the tropics, landing months later on the shores of Indonesia, Australia, and South America. Ten thousand others headed north, however; by the end of the year, they were floating off Alaska and heading back westward. It took three years for these ducks to circle east to Japan, past the original drop site, before being carried back to Alaska on a current known as the North Pacific gyre and continuing north toward the Arctic. Many of them became stranded as the current took them through the Bering Strait, the body of water that divides Alaska from Russia. In 2000, eight years after their journey began, the ducks were reported to have arrived in the North Atlantic Ocean. By now, the once-bright yellow ducks were bleached white by the Sun and saltwater, but many were still floating strong. In 2007, some of them reached the shores of southern England and Ireland.

Ocean Currents



Cold currents

1. California Current
2. Humboldt Current
3. Labrador Current
4. Canaries Current
5. Benguela Current
6. Falkland Current
7. West Australian Current
8. Okhotsk Current

Warm currents

1. North Pacific Drift
2. North Equatorial Current
3. Equatorial Countercurrent
4. South Equatorial Current
5. West Wind Drift
6. Gulf Stream
7. North Atlantic Drift
8. North Equatorial Current
9. Equatorial Countercurrent
10. South Equatorial Current
11. Brazil Current
12. West Wind Drift
13. Monsoon Current
14. Equatorial Countercurrent
15. South Equatorial Current
16. Mozambique Current
17. West Wind Drift
18. Japan Current
19. North Equatorial Current
20. Equatorial Countercurrent
21. South Equatorial Current
22. East Australian Current

The network of circulation in Earth's oceans is known as the Global Conveyor Belt.

Understanding currents is important to oceanographers in their studies of how currents transport bacteria, fish, heat, and chemicals such as salts, oxygen, and carbon dioxide around the planet. Knowledge of ocean currents is also extremely important for ship navigation, search and rescue at sea, and tracking the spread of pollution. Sailors have known about the movements of currents for thousands of years. Early studies of ocean circulation relied on drift bottles released into the current. These bottles contained message cards asking the finder to return the card, along with a description of where and when the bottle was recovered. Only in the past century or so, however, have oceanographers discovered what drives the currents and been able to chart their courses throughout the world's oceans. Today, many oceanographers use satellites and other technology to monitor currents. One method that today's oceanographers use to learn about ocean currents is the monitoring of networks of floating buoys. Buoys work like miniature weather labs that bob around the surface of the ocean and can measure wind speed, air temperature, sea-surface temperature, wave height, and water currents.

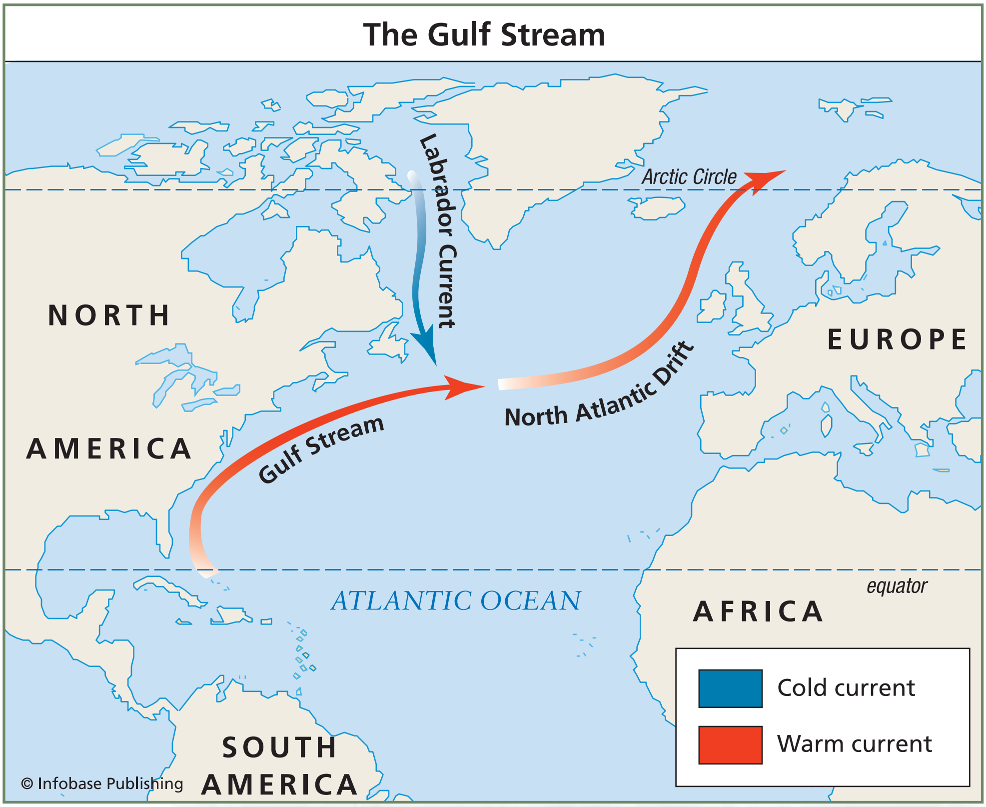
Surface currents—currents in the top 1,500 feet (455 m) of the ocean—travel about 6 miles (10 km) per day. The Earth's spin causes the world's winds and surface currents to veer off from their otherwise straight path. This movement is called the **Coriolis effect**. North of the equator, the effect deflects currents to the right (or clockwise). South of the equator, it causes currents to veer to the left (or counterclockwise). This, along with the shape of the continents, makes surface currents flow in six large rotating loops called **gyres.** In the north, ocean waters circulate in two huge, clockwise gyres: the North Pacific gyre and the North Atlantic gyre. The Southern Hemisphere has four counterclockwise gyres. Water currents can also move up and down. In some places, winds cause surface waters near the coast to move offshore, allowing colder, deeper water that is rich in minerals and dissolved plant and animal remains to rise to the surface. This phenomenon is called **upwelling.** The nutrients in the cold, deep water provide food for marine life near the surface, so upwelling areas have rich populations of fish. Strong upwelling currents off the coast of Peru, for example, feed gigantic schools of anchovies. Larger fish, birds, and human fishers catch millions of these fish. Every few years, however, **El Niño** puts the brakes on this bountiful upwelling.

The Stormy Infant: El Niño

In the 1500s, fishers in South America became curious about a current of unusually warm water that came to their shore every few years near Christmastime. They named the warm water El Niño, which means *the infant* in Spanish. Once thought to affect only a narrow strip of water off Peru, El Niño is now recognized as a large-scale oceanic warming that affects most of the tropical Pacific. The weather effects related to El Niño extend throughout the Pacific to eastern Africa and beyond. Scientists are interested in El Niño because of how its warm waters cause the air above it to also become warmer. Just as a warm bath heats the air in the bathroom and makes it steamy, the same thing happens here—only this time, there are millions and millions of bathtubs worth of warm water. All of that moist, warm air has to go somewhere, and when that warm air moves away, it carries the moisture with it. Once it starts to cool, rain clouds form. The result is flooding in South American countries along the coast. Normally, during non-El Niño conditions, currents push warm surface water in the tropical Pacific Ocean to the west. This allows cold water from the deep ocean to rise along the west coast of South America. During El Niño years, however, warm surface water sloshes eastward and gathers along the eastern edge of the Pacific Ocean, where the climate, land, and people are unprepared for the unusual weather events that El Niño brings in the form of heavy rains, mudslides, and flooding.

The effects reach far beyond South America. As the mound of warm water in the western Pacific moves east, the area of heavy rain above it tags along. As a result, Southeast Asia and Australia experience less rainfall. One of the strongest El Niños occurred in 1982–1983. Its effects included torrential storms throughout the southwest United States while, at the same time, Australia had one of its worst droughts ever recorded.

Two of the largest ocean currents are the Antarctic Circumpolar Current, which circles eastward around Antarctica, and the speedy Kuroshio Current, which travels off of Japan's coast and moves up to 75 miles (113 km) in a day. The best-studied current is probably the **Gulf Stream**, a fast, warm, intense current that is part of the North Atlantic gyre. It was first mapped in 1770 by Benjamin Franklin. The story begins in 1768, when Franklin was the postmaster general for the American colonies. That year, British authorities summoned him to London. They wanted to know why letters took much longer to reach the port of New York than they took to reach New England ports when the two

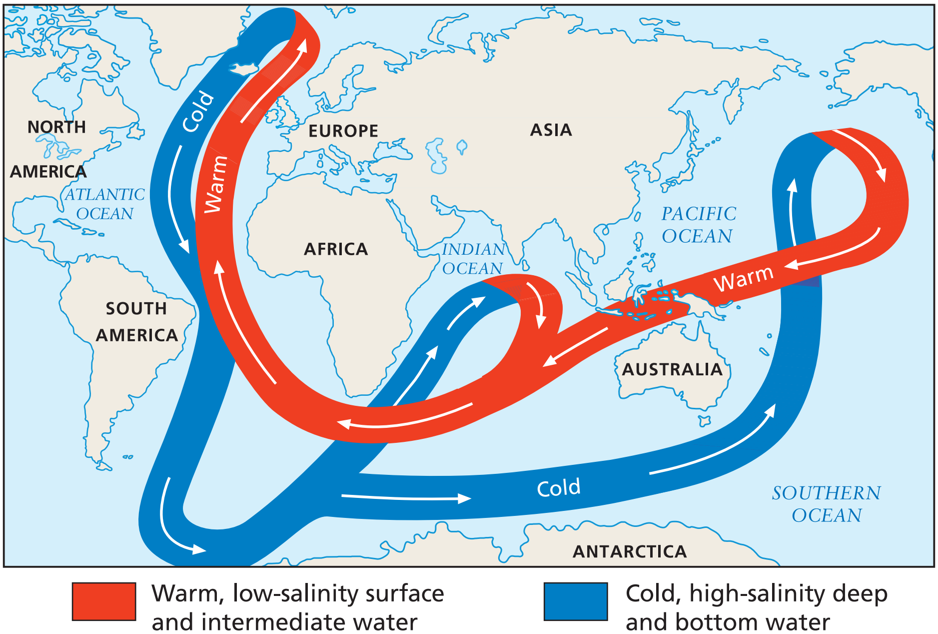


The Gulf Stream is probably the best-studied current. It is the reason why Europe enjoys a relatively mild climate.

locations were "scarcely a day's sail apart" and why westward mail from Europe to America took weeks longer than the eastbound ships from America to Europe. Franklin did not have an answer, but he began to investigate. He found one piece of evidence right in his own journal. On an earlier return trip from London, Franklin had noted that after several weeks at sea the water's color began to change. There were "hot damp winds," he noted in a journal entry, along with "an abundance of grass" and other seaweed visible in the water. To Franklin, the warmer air and warmer water suggested that the ship must be very near the coast, but, in fact, the ship was nowhere near land. And, indeed, after six days, the water returned to its former darker color, and the hot wind and abundant seaweed disappeared.

The warm water that Franklin saw came from the Gulf Stream. This current begins off the coast of Florida, where it is 50 miles wide (80 m), a quarter-mile deep (0.4 km), and moves 10 cubic miles (42 cubic km) of water every hour. It flows too quickly for its warm waters to mix with the surrounding colder seas. The current eventually slows down as it crosses the Atlantic and approaches Europe, but it still carries enough warm tropical water to help keep the climate of northern Europe relatively mild. For example, the west coast of northerly Norway enjoys temperatures that are a good 50°F (10°C) warmer than normal for its latitude. Without the Gulf Stream, the city of Dublin would have an arctic climate. Deep-ocean currents are a more recent scientific discovery. They move more slowly than surface currents—less than 350 feet (105 m) a day. Deep-ocean currents begin at the poles, in the Arctic and Southern oceans. When icebergs form, most of the salt in the water is left behind in the sea, so that the icebergs are made of freshwater. This means that the surface of the sea underneath an iceberg is saltier than normal seawater. The saltier that water is, the heavier it is, and so this extra-salty, cold water sinks to the ocean floor. Sinking cold water helps keep the world's oceans circulating and is an important driving force behind the world's deep-ocean currents. Cold water flows from the poles along the seafloor toward the equator where it warms

Ocean Conveyor Belt



The global circulation pattern of the planet's oceans is called the Great Ocean Conveyor Belt.

up, becomes lighter, and so rises to the surface. The water then flows back to the poles as warm surface currents, only to begin the cycle again. This global circulation pattern of the planet's oceans is known as the Great Ocean Conveyor Belt. The belt helps to distribute warm and cold water around the world and has a huge effect on climate. The Gulf Stream itself is part of the conveyor belt.

The conveyor belt begins in the North Atlantic, where the water grows cold and salty. Eventually, the cold, salty water sinks to feed a sluggish current called the North Atlantic Deep Water. With a flow volume 20 times that of all the world's rivers combined, the Deep Water runs southward along the ocean floor. It may take another 1,000 years for this water to reach the surface again. Once it does, however, it will continue to do what water is always doing: cooling and heating, eroding and building, transporting and depositing.

From currents to waves and from rivers to rain, water is always on the move. The cycle of water is a never-ending journey that travels to all heights and depths of the globe. You might not always know where water will go, but you can be sure that it is changing our world, one drop at a time.

Glossary

Abyssal hill A hill on the abyssal plain, ranging up to several hundred feet high and several miles in diameter.

Abyssal plain The flat, deep ocean floor, almost featureless because of a thick layer of sediment that covers the hills and valleys.

Aquifer An underground layer of rock and sand that contains usable amounts of water.

Backwash The water that rolls back down a beach after a wave has broken.

Barrier island A long, narrow, wave-built island separated from the mainland by a lagoon.

Barrier lake A lake formed by glaciers; glaciers create a buildup of rocks, which stop water from flowing away.

Basalt A common gray-to-black volcanic rock.

Bathymetric map A map illustrating the shape and depth of the ocean floor.

Blowhole A hole in the top of a sea cave through which air and seawater blow. Waves entering the mouth of the cave can be funneled up toward the blowhole and result in quite spectacular splashes.

Brackish Water that is saltier than freshwater, but not as salty as seawater; may result from mixing of seawater with freshwater, as in estuaries.

Braided river A river that has been forced to divide into several channels separated by banks or islands.

Channel The bed of a stream or river.

Continental rise The gently sloping surface located at the base of a continental slope.

Continental shelf The relatively shallow, flat portion of the seafloor extending from the shoreline to the shelf break, where the seafloor abruptly slopes downward.

Continental slope The slope that extends from a continental shelf down to the deep ocean.

Coriolis effect Tendency for any moving body, such as an ocean current, to drift sideways from its course because of the Earth's rotation. In the Northern Hemisphere, the effect turns the current to the right; in the Southern Hemisphere it turns to the left.

Crust The hard outer layer of the Earth.

Delta A large deposit of sediment that forms where a river enters a standing body of water such as a lake or ocean.

Distributaries Small, shifting river channels, located in deltas, that carry water and sediment away from a main river and across a delta.

Drainage basin The total area of land that contributes runoff to a river. Also referred to as a *watershed*.

El Niño The appearance of unusually warm surface waters of the Pacific Ocean along the tropical western coast of South America every few years. It can affect climate on a large scale.

Erosion lakes A lake in a bowl-shaped basin that has been worn away by a glacier.

Estuary The wide part of a river near its mouth where the river's freshwater mixes with salty water from the sea.

Evaporation The process of liquid water becoming water vapor.

Fetch The distance over which an ocean wind is blowing.

Fjord A deep, narrow, steep-walled, U-shaped valley that was carved by a glacier and is now occupied by the sea.

Floodplain A flat area of land bordering a river that has been formed by the river's silt deposits.

Fracture zone Long cracks in the seafloor associated with mid-ocean ridges.

Groundwater The water beneath the Earth's surface, beneath the water table; it fills cracks, crevices, and pores in rocks and soil.

Groundwater discharge lake A lake that is formed when groundwater rises to the Earth's surface.

Gulf Stream A warm ocean current that flows from the Gulf of Mexico northward through the Atlantic Ocean.

Guyot A seamount, the top of which has been flattened by erosion or wave action.

Gyre A giant circular oceanic surface current.

Habitats The natural places where plants and animals live.

Headlands Areas of land protruding out to sea formed of resistant (harder) rock. They help protect the bay that forms between them from heavy waves.

Headwaters The upper portions of a drainage basin where the tributaries of a stream first begin to flow.

Hydrologic cycle The natural cycling of Earth's water between the atmosphere, surface, and underground through the processes of evaporation, transpiration, percolation, infiltration, runoff, and precipitation; it is also known as the *water cycle*.

Hydrothermal vents Openings in rocks where warm or hot fluids seep out.

Hypopycnal flow The flow of less-dense freshwater on top of denser, saltier seawater.

Interlocking spurs Tongues of land on the sides of a river valley around which a river twists. Typically found in the upper river region.

Kettle A depression formed in glacial deposits when a buried block of ice, left behind by a retreating glacier, melts. Lakes, called kettles lakes, often form as a result.

Lagoon A shallow stretch of seawater partly or completely separated from the open ocean by a long, narrow strip of land, such as a reef or a barrier island.

Levee A raised bank of sediment or other material along a river. Can be naturally occurring or man-made. Often constructed by people to prevent flooding.

Longshore current An ocean current that moves parallel to the shore, caused by waves that hit a coast at an angle. Longshore currents can transport large amounts of sand and sediment.

Meander A loop-like bend in a river as it flows across flat country.

Mid-ocean ridge A long, undersea mountain chain where new ocean floor is produced.

Mouth The place where a river flows into an ocean or lake; the "end" of a river.

Mudflat A flat area along the coast, covered with a thick layer of mud or sand. Mudflats are usually under water at high tide.

Neap tides Small tides that occur when the gravitational forces of the Moon and the Sun are perpendicular to one another.

Organic Matter Materials and debris that originated as living plants or animals.

Oxbow lake A horseshoe-shaped lake formed on a river when a meander has been cut and abandoned.

Pangaea The super continent that broke apart 200 million years ago to form the present continents.

Panthalassa The gigantic ocean that existed 250 million years ago. It was the predecessor to the Pacific Ocean.

Plates Giant, rigid slabs of the Earth's crust. The plates "float" on a dense, fluid layer just beneath them.

Precipitation Movement of water from the atmosphere to the land or to a surface-water body. Rain, hail, snow, dew, and sleet are all examples of precipitation.

Raised beach A beach left stranded high on a cliff face after a fall in sea level.

Reservoir An artificial lake used to collect and store water.

Reverse osmosis A filtration process that removes dissolved salts and metals from water by forcing it through a semipermeable membrane.

Rift valley A long, straight, deep valley produced by the separation of continental plates.

Rill A tiny streamlet of water that often flows into larger streams of water and sometimes eventually into a river.

River terrace A step-like accumulation of river deposits along the sides of a river valley that were deposited when river levels were higher.

Rogue waves Unexpectedly high open-ocean waves.

Salinity A measure of the quantity of dissolved salts in ocean water. It is typically measured in parts per thousand by weight.

Salt marsh A coastal wetland flooded regularly by tidal, brackish water.

Sand bar An area in shallow water where wave or current action has created a small, long hill of sand.

Seafloor spreading The movement of two oceanic plates away from each other, resulting in the formation of new oceanic crust and a mid-ocean ridge.

Seamount A volcanic mountain rising from the sea floor that does not extend above sea level.

Silt Very fine grains of sediment that are carried and deposited by a river.

Sonar A method using underwater sound waves to determine depth; abbreviation for "Sound Navigation And Ranging."

Spit Narrow, fingerlike ridge of land extending into a body of water, usually built up by a longshore current bringing sand.

Spring tides Higher than normal tides observed every two weeks when the Earth, Sun, and Moon align.

Subduction zones Process where an oceanic plate and a tectonic plate move toward each other with the oceanic plate plunging beneath the other tectonic plate.

Surf The result of waves breaking on shore causing air to mix with the water.

Swash The water moving up a beach from a breaking wave.

Swells The up-and-down wave pattern in the open ocean.

Tectonic lake A lake located in a steep-sided valley that was formed when land slipped down between deep cracks in the Earth's surface.

Tidal bore A high, wall-like wave that rushes up an estuary (and sometimes also up a river) as the tide rises.

Tidal bulge The bulge of water on each side of the Earth caused by the gravitational tug of the Moon and the Sun on the world's oceans.

Tidal creek Flow of water produced in response to a rising or falling tide. The currents can flow into or out of a bay, causing the water to rise or fall.

Tidal range The difference in height between low tide and high tide.

Tides The regular rise and fall of water level in the ocean, caused by the pull of the Sun and Moon on Earth.

Tributary A stream or river that flows into a larger river.

Tsunami A large sea wave normally produced by sudden movement of the ocean floor caused by an earthquake or volcanic eruption. These waves can travel at high speeds across an ocean and cause great destruction when they reach land.

Turbidity current An underwater avalanche of sediment and water that speeds down the continental slope. It can cause large canyons and gullies to form.

Upwelling The rising of cold water from the deeper areas of the ocean to the surface.

Volcanic lake A lake that forms in volcanic craters after the volcano has been inactive for some time. Water in these types of lakes may be fresh or highly acidic.

Water erosion The wearing away and movement of rocks and sediment by water.

Water table Area beneath the Earth's surface, below which all pore spaces are filled with water and above which the pore spaces are filled with air. The water table rises after rainfall and falls during dry weather.

Wave crest The highest point, or peak, of a wave.

Wavelength The distance from crest to crest or trough to trough of a wave.

Wave period The time it takes for two successive wave crests to pass a fixed point.

Wave trough The lowest part of a wave.

Whirlpool A large, swirling body of water produced by ocean tides.

Bibliography

Benke, Arthur C. and Colbert E. Cushing, eds. *Rivers of North America*. Burlington: Academic Press, 2005.

Garrison, Tom. *Oceanography*. 3rd ed. Belmont, Calif.: Wadsworth, 1999.

Haslett, Simon K. *Coastal Systems*. New York: Routledge, 2000.

Hotz, Robert Lee. “Miles Below Antarctic Ice, A Freshwater Lake May Harbor Ancient Life.” *Los Angeles Times*. March 3, 2001.

Kerr, Richard A. “Manganese Nodules Grow by Rain from Above.” *Science Magazine* Vol. 223 No. 4636 (February 10, 1984): 576–577.

Lerner, K. Lee and Brenda Wilmoth Lerner, eds. *UXL Encyclopedia of Water Science*. Detroit: UXL, 2005.

Pielou, E. C. *Fresh Water*. Chicago: University of Chicago Press, 1998.

Rignot, Eric and Pannir Kanagaratnam. “Changes in the Velocity Structure of the Greenland Ice Sheet.” *Science Magazine* Vol. 311 No. 5763 (Feb. 17, 2006): 986–990.

Sigmundsson, Freysteinn. “Plate Tectonics: Magma Does the Splits.” *Nature*. Vol. 442 (July 20, 2006): 251–252.

Stock, Joann M. “The Hawaiian-Emperor Bend: Older Than Expected.” *Science Magazine* Vol. 313 No. 5791 (September 1, 2006): 1250–1251.

Thurman, Harold V. *Introductory Oceanography*. 5th ed. Columbus, Ohio: Merrill Publishing, 1988.

U.S. Geological Survey. "Gas (Methane) Hydrates—A New Frontier." Available online. September 1992. Accessed August 18, 2008. URL: http://marine.usgs.gov/fact-sheets/gas-hydrates/title.html.

Woodward, Colin. "Netherlands Battens Its Ramparts Against Warming Climate." *Christian Science Monitor* September 4, 2001.

Further Reading

Arato, Rona. *World of Water*. New York: Crabtree Publishing Company, 2004.

Bailey, Jaqui. *Drop in the Ocean: The Story of Water*. Mankato: Picture Window Books, 2004.

Davis, Richard. *Evolving Coasts*. New York: W.H. Freeman, 1996.

Earle, Sylvia. *National Geographic Atlas of the Ocean: The Deep Frontier*. Washington, DC: National Geographic, 2001.

Groves, Don. *The Oceans: A Book of Questions and Answers*. New York: Jossey-Bass, 1989.

Kunzig, Robert. *Mapping the Deep*. New York: W.W. Norton & Company, 2000.

——. *The Restless Sea: Exploring the World Beneath the Waves*. New York: W.W. Norton & Company, 1999.

Outwater, Alice. *Water: A Natural History*. New York: Basic Books, 1997.

Pearce, Fred. *When the Rivers Run Dry: Water—The Defining Crisis of the Twenty-first Century*. Boston: Beacon Press, 2007.

WEB SITES:

42explore: Rivers
http://42explore.com/rivers.htm.
Good clearing-house of river-related Web sites and news.

American Rivers
http://www.americanrivers.org/
Conservation organization dedicated to protecting and restoring healthy natural rivers and the variety of life they sustain for people, fish, and wildlife.

The Franklin Institute. El Niño
http://www.fi.edu/weather/nino/nino.html
Information, activities, and resources about the science of El Niño.

The Franklin Institute. Undersea and Oversee: The past, present, and future of our oceans.
http://www.fi.edu/oceans/oceans.html
Resources and information about the oceans.

Geology for Kids
http://www.kidsgeo.com/geology-for-kids/0074-erosion-rivers-lakes-streams.php
Erosion by Water Processes: Examines erosion and its effect on the landscape.

LakeNet
http://www.worldlakes.org/
A global network of people and organizations working for the conservation and sustainable management of lakes. Site includes reasons why lakes are important, amazing lake features, pollution, invasive species, fisheries, treaties, and more.

Missouri Botanical Gardens. Ponds and Lakes
http://www.mbgnet.net/fresh/lakes/index.htm
Overview of lakes and ponds and how they form. Includes many graphics and a resource page.

Missouri Botanical Gardens. Rivers and Streams
http://www.mbgnet.net/fresh/rivers/index.htm
Overview of rivers and streams and how they form. Includes river facts and a resource page.

NASA Earth Observatory. The Water Cycle
http://earthobservatory.nasa.gov/Library/Water/
Detailed overview and facts about the water cycle.

National Oceanic and Atmospheric Administration's Ocean Portal
http://www.noaa.gov/ocean.html
The NOAA protects, preserves, manages, and enhances the resources found in 3.5 million square miles of coastal and deep-ocean waters. Site offers full directory of all NOAA's resources and news.

Office of Naval Research. Oceanography
http://www.onr.navy.mil/focus/ocean/
Packed with ocean facts and resources, including an "Ask the Expert" section.

PBS. The Wrath of El Niño
http://www.pbs.org/newshour/forum/october97/el_nino_10-3.html
Answers questions and provides resources about El Niño.

The Science of Volcanic Lakes
http://pasternack.ucdavis.edu/lakes.html
Contains information on how volcanic lakes work and details about many specific lakes.

U.S. Environmental Protection Agency. Lakes and Ponds
http://www.epa.gov/bioiweb1/aquatic/classify.html
Describes types of lakes and ponds, how they were formed, and their ecology.

U.S. Environmental Protection Agency. Rivers and Streams
http://www.epa.gov/bioiweb1/aquatic/river-r.html
Contains information about rivers and streams and how to keep them healthy.

U.S. Geological Survey. Earth's Water: Rivers and Streams
http://ga.water.usgs.gov/edu/earthrivers.html
Discusses rivers and streams including what they are, their sources, and their impact on the landscape.

Woods Hole Oceanographic Institution
http://www.whoi.edu/
Research news about a wide variety of ocean topics.

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About the Author

Journalist **GRETEL H. SCHUELLER** writes about science and the environment. Her articles have appeared in many magazines, including *Audubon*, *Discover, Hooked on the Outdoors, National Wildlife, New Scientist, Popular Science*, and *SKI*. She was an editor at several national publications, including a kids' science magazine. She is also an associate professor at the State University of New York in Plattsburgh, where she teaches journalism. She earned her master's degree in science journalism from New York University. Before becoming a writer, she studied marine science and traveled to the cold, dark depths of the Baltic Sea. Now living on the shores of Lake Champlain in New York, she gets to enjoy one of water's nicer sides.