Earth's Changing Surface
Content Background Document

1. Introduction

As we begin our content exploration of Earth's changing surface, take a moment to think about what you already know about this topic.

You probably know the names of many common landforms, such as mountains, rivers, lakes, canyons, prairies, mesas, and plains. It's likely you know these landforms were shaped by processes that have occurred throughout history and will continue to transform the landscape. Most likely you know something about erosion—how water and gravity move materials from the tops of mountains, hills, fields, and plains into streams and then rivers and eventually deposit these sediments in river deltas. You might know something about weathering—the ways that the tallest mountains and largest boulders and rocks are broken down until they become grains of sand or dirt or are dissolved into their mineral components in the water. You might even know something about how and why mountains form—how Earth's surface is pushed and pulled when the tectonic plates that make up Earth's crust collide, divide, and grind past one another.

But how *deep* is your understanding? Can you use your knowledge to explain why mountain ranges exist in certain places on Earth but not in others? Or why volcanoes erupt all around the Pacific Ocean, but none occur around the Atlantic Ocean? Are you clear about why it's important for your students to know about the processes that cause Earth's surface to build up and wear away? Why is it important for *you* to learn about them?

This document will challenge you to broaden and deepen your understanding about Earth's changing surface based on what you already know. It's designed to support and further your content learning about the dynamic nature of Earth's surface, including ideas about the movement of Earth's tectonic plates, the uplift of mountain ranges, and the processes that break down the tallest mountains until they're once again flat plains. The goal is for you to develop a conceptual understanding of these science ideas so you'll be able to more effectively teach elementary students.

This content is written with you, the teacher, in mind. The subject matter is tied to the model lessons you'll be teaching, but the concepts are presented at a higher level to equip you with the tools and background you'll need to guide student learning. After all, teachers should know more than their students about the science ideas they'll be teaching!

2. Getting Started: A Dynamic Earth

The goal of this unit is for you and your students to see that Earth is always changing. Energy from deep inside Earth causes the surface to move, and as a result, towering mountain ranges like the Rockies are built up. All the while, rain falls, rivers flow, wind blows, and glaciers scrape across mountainsides, tearing apart Earth's surface and breaking down mountains into tiny grains of sand that are carried away to the oceans. You may be surprised to learn that the rolling, gentle Appalachian Mountains in the eastern United States were once as jagged and tall as the Himalayan Mountains of China and Nepal, but over long periods of time, the forces of rain, wind, and gravity transformed them into lowly vestiges of their once stately grandeur (figure 1).

Photo courtesy of Partha Sarathi Sahana, Flickr

Photo courtesy of Ken Thomas, Wikimedia

Figure 1. Note the differences between the relatively younger Himalayan Mountains (top) and the older, more eroded Appalachian Mountains (bottom).

A key idea to keep in mind is that Earth's surface is continually in a state of being built up in some areas and torn down in others. The "stuff" (matter) that makes up Earth hasn't changed; it's just constantly rearranged and recycled through natural processes that have occurred throughout Earth's history.

STOP AND THINK

Pick up a pebble or a piece of dirt from the school grounds and imagine the journeys and changes it has experienced throughout Earth's long history.

Earth has been around for a long time. Evidence from the chemical makeup of the most ancient rocks indicates that Earth is about 4.6 billion years old. It hasn't always looked the way it does today. Scientists believe that at first Earth was a ball of materials that accumulated from particles in space randomly hitting each other until they became big enough to exert a gravitational force. This gravity pulled in more and more space debris, raining down rocks, ice, and dust to pelt the planet and heat it up until all the material melted into one fiery, liquid ball. The densest material sank to the center of this hot, moving mass, while lighter material rose to the planet's surface. Eventually the storm of space debris ended, and the surface cooled to form a thin, solid crust. However, Earth's center continues to seethe with hot, melted materials that roil and churn over a long period of time to wreak havoc in complex ways on Earth's surface.

There are two models for talking about the layers of Earth. The first model (figure 2), which is more simplistic, is often used in discussions with students. It presents Earth as having a crust, a mantle, and a core (which is sometimes divided into an inner core and an outer core). However, scientists use a more complex model to represent as accurately as possible the various layers of Earth (figure 3). This model divides Earth's outermost layers into the *lithosphere*, which consists of the crust and the uppermost layer of the mantle, and the *asthenosphere*, which is a softened, fluid-like layer of rock in the upper mantle. In the scientific model, the rigid layer of the lithosphere is broken up into several major and minor plates that vary in density and move or "float" on the viscous layer of the asthenosphere. Scientists believe that convection and dissipation of heat from the mantle cause these plates to move.

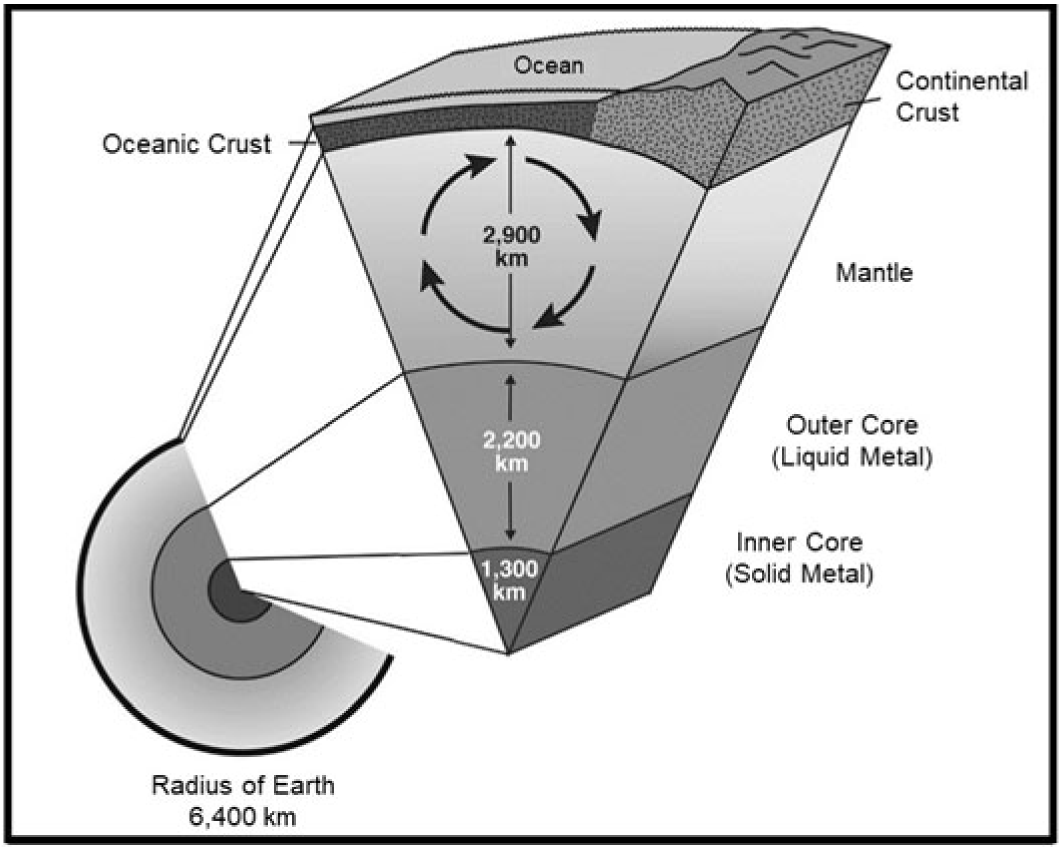

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Figure 2. Simple diagram of Earth's interior

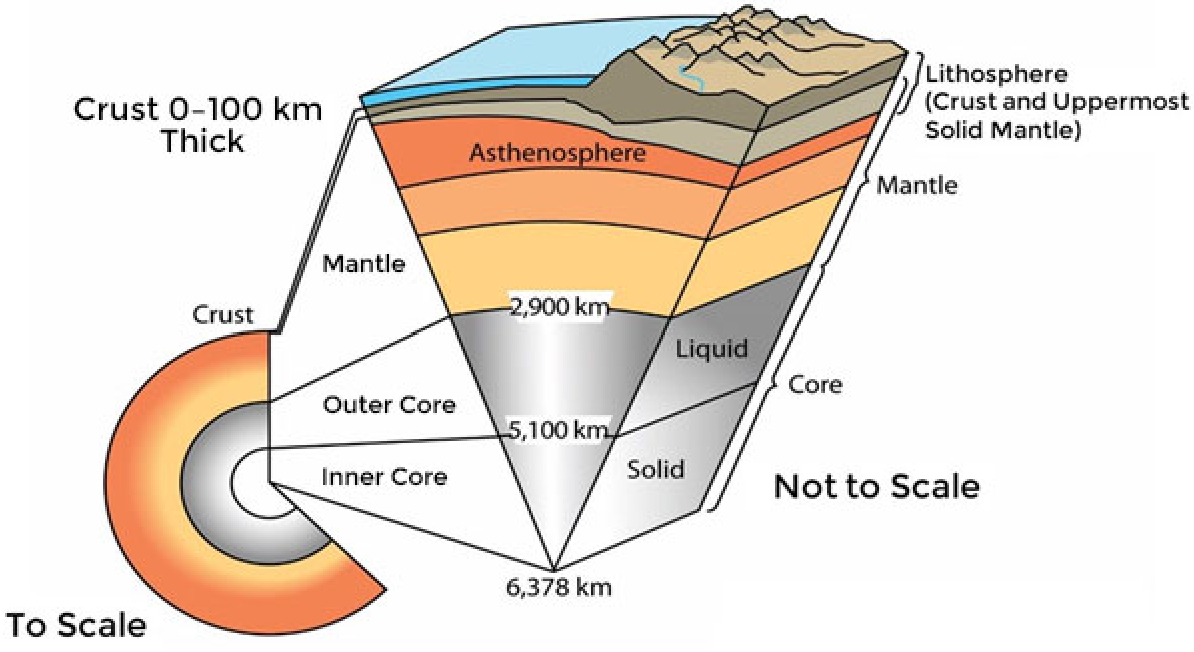

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Figure 3. A more scientific diagram of Earth's interior

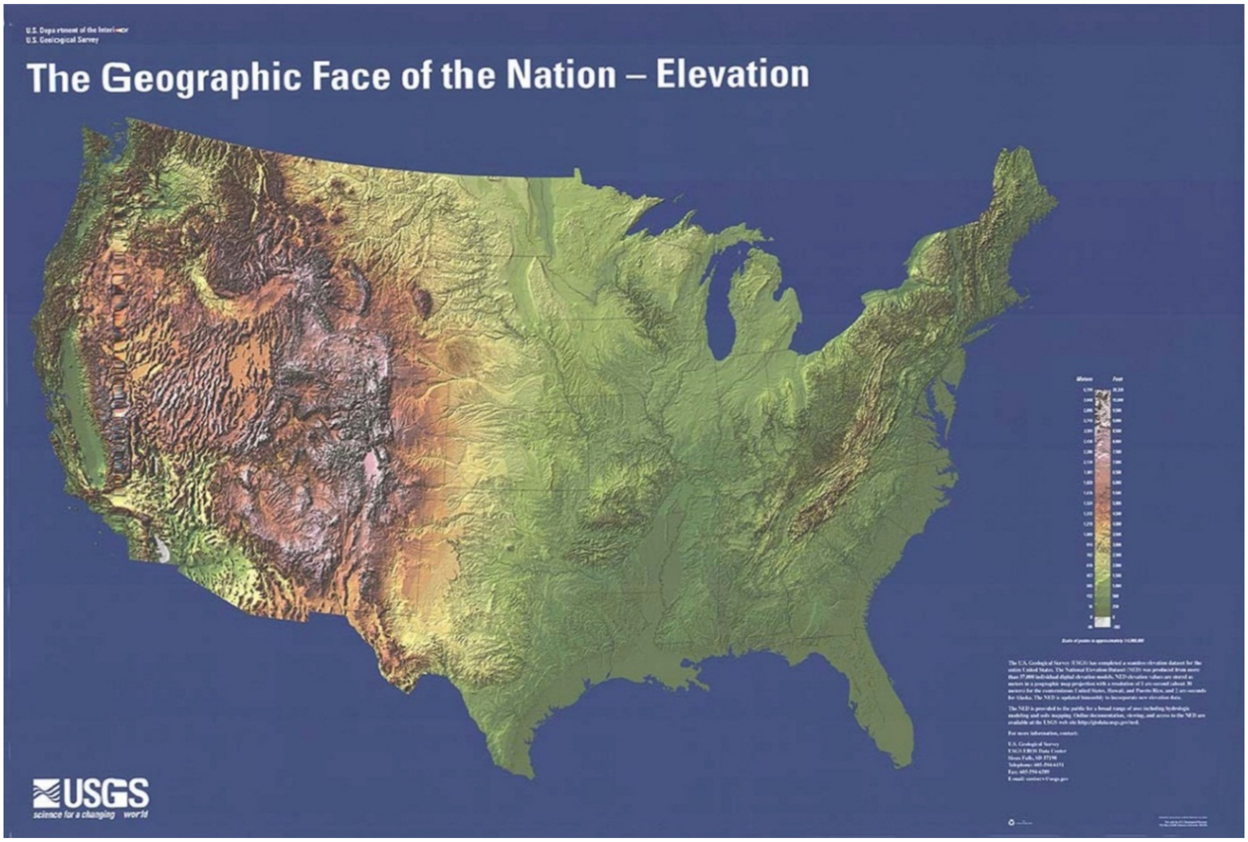
Despite the different ways we talk about Earth's layers, the big idea for students to understand is that they vary in density and rigidness, allowing for a dynamic system. The outermost layer—the crust—is composed of rock, sediment, sand, and soil and represents less than 0.1% of Earth's total volume. It's a very thin layer compared to the massive interior of Earth. Oceans ebb and flow over about 70% of Earth's crust, and continents sit atop the remaining crustal area. The large interlocking sections, or plates, that make up Earth's crust move slowly in response to the movement of the asthenosphere (part of the upper mantle) below. Due to this constant motion, Earth's surface hasn't always looked the way it does today. Continents and oceans have shifted—combining and separating in different configurations over the course of Earth's history. Occasionally all the land masses have converged into one large supercontinent, called *Pangaea*, meaning "all land." The most recent Pangaea broke apart about 325 million years ago, but vestiges of earlier continental collisions and separations indicate that this wasn't the first time the continents merged—and all we know about Earth's processes leads to the conclusion that it won't be the last.

3. Landforms

Let's consider what we know about Earth's surface. First, we know that it's made up of many different types of landforms. A *landform* is a naturally occurring physical feature of Earth. We typically think of landforms as parts of the terrain—or land—and also various kinds of water bodies. So when we define landforms, we include descriptors like hills, ridges, cliffs, mountains, valleys, plains, canyons, mesas, rivers, peninsulas, ponds, lakes, oceans, bays, deltas, and seas. Landforms don't include man-made features—such as canals, ports, and harbors—or geographic features—such as deserts, forests, and grasslands. Characteristic physical attributes, such as shape, elevation, and slope, categorize landforms.

Students tend to see landforms as permanent features of Earth. They assume that mountains and oceans have always been here and will always remain the same. An important goal of these lessons is to help students change this perspective and begin viewing landforms as constantly changing. This is a big conceptual shift for students to make, so it won't be easy.

You may have noticed that certain landforms occur in distinct patterns around the globe. For example, most volcanoes occur either in a ring around the Pacific Ocean (dubbed the "Ring of Fire" in reference to numerous volcanic eruptions) or along the Indonesian island archipelago. The western half of the United States has tall, jagged mountains—96 of which tower above 14,000 feet in elevation—with swiftly flowing rivers. But the eastern half of the country has shorter, rolling mountain ranges and meandering river systems. The highest peak in the Appalachians is Mount Mitchell in North Carolina, rising only 6,684 feet above sea level. The mountains in the eastern United States have geology strikingly similar to mountains in Scotland and Scandinavia. The distinct pattern represented in the positions of mountains, valleys, and plains has led scientists to ask why certain landforms occur in some places and not in others (see figure 4).



Courtesy of USGS

Figure 4. Topography of the United States

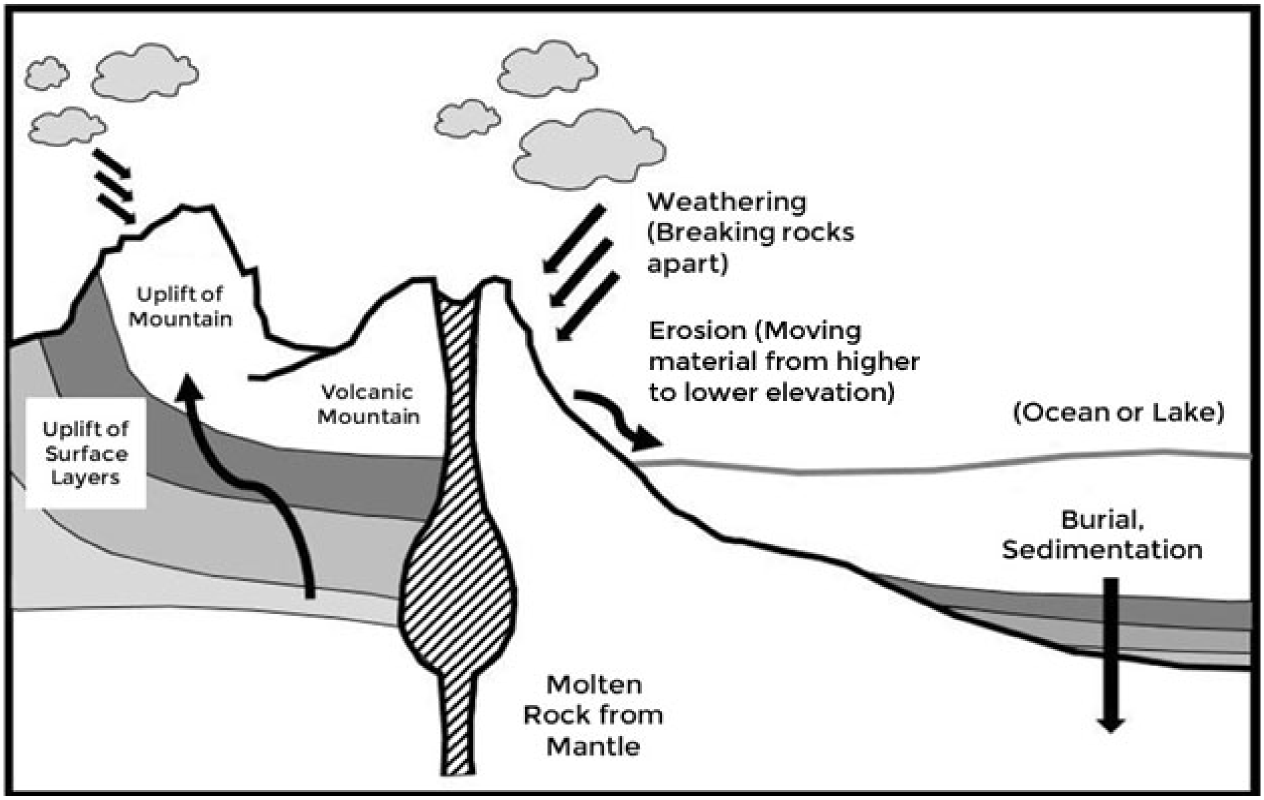
STOP

STOP AND THINK

Why is Earth flat in some places and mountainous in others?

4. Understanding Earth's Processes

As early as the 1700s, Scottish naturalist James Hutton became convinced that the geological forces at work in his time—forces such as erosion and weathering that the human eye barely notices and yet have an immense impact—are the same forces that functioned in Earth's distant past. In this view, the same natural laws and processes that operate on Earth now have operated in the past. This philosophy of uniformitarianism included the concept that the present is the key to the past, and changes on Earth function at the same rates across time. Hutton used uniformitarianism to explain the geologic patterns seen on Earth, describing the formation of landforms on Earth as a continuous cycle in which rocks and soil are washed into the sea, compacted into bedrock, forced up to the surface by volcanic processes, and eventually worn away into sediment once again (see figure 5). "The result, therefore, of this physical inquiry," Hutton concluded, "is … that we find no vestige of a beginning, no prospect of an end" (Hutton, 1795).



Courtesy of Cal Poly Pomona

Figure 5. Processes that occur on Earth today are the same as those that have occurred throughout Earth's history.

Although uniformitarianism is still one of the fundamental principles of earth science, a huge breakthrough in our understanding of landforms occurred in the twentieth century with Alfred Wegener's proposition that continents move. This radical idea challenged the everyday perception that we're standing on solid, unmoving ground. Wegener noted that the shapes of the continents on either side of the Atlantic Ocean, particularly Africa and South America, seem to fit like interlocking puzzle pieces. Similarly, fossils of certain ancient organisms were found on continents on opposite sides of the Atlantic, and bands of similar types of rock matched up in Africa and South America as if these continents had at one time been contiguous (figure 6).

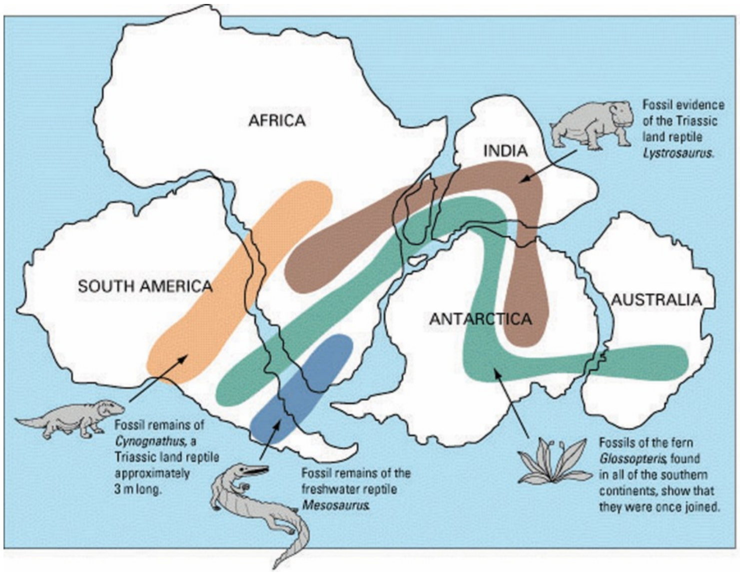


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Figure 6. Similar fossils are found in Africa and South America.

Reasoning from these data, Wegener proposed that continents weren't always where they are today but moved slowly over time. Unfortunately, during Wegener's lifetime, his theory gained little acceptance. It was only between the 1940s and the 1960s, with the advent of new technologies enabling scientists to gather oceanic data, that geologists began to accept and expand on Wegener's ideas and construct today's modern theory of plate tectonics. Sonar and radar images allowed scientists to map the ocean floor, revealing prominent undersea ridges that we recognize today as areas where large sections of Earth's crust have pulled apart. Submarines allowed for the collection of rocks on the ocean floor, which, when tested, indicated that very young rocks were found close to the ridges, with bands of sequentially older rocks on either side. Additional technologies provided evidence that the magnetic orientation of rocks was similarly paired on either side of the undersea ridges.

Today we understand that continents sit atop massive, interlocking sections of Earth's crust that are slowly moving. These sections are referred to as *tectonic plates*. The word *tectonic* comes from a Latin word that means "building." This emphasizes the role these moving plates play in building up Earth's surface.

The theory of plate tectonics brought about a revolution in earth science because it provided a unified explanation for many scientific observations, including locations of earthquakes, mountain ranges, and active volcanoes. The theory of plate tectonics explains most geologic features so well that geologists can't envision any other explanation of Earth's surface and its various features. Before we can fully understand the movement of these puzzle-like pieces of Earth's crust, we first need to understand something about the forces occurring inside the planet.

5. Earth, Inside and Out

In general, Earth is divided into three main layers: a very thin outer *crust*, a thicker *mantle*, and a metallic *core*. Exactly how these layers interact and what they're made of is still open to debate. Since Earth's crust is the only layer geologists can study firsthand, they must use indirect data, such as the path of earthquake waves as they travel through Earth's interior, to make inferences about the mantle and the core.

The outermost layer of Earth—the layer we walk on—is a thin, rocky skin, or crust, that covers the planet. A good analogy is a postage stamp stuck on a billiard ball. Earth's crust is quite thin in relation to the rest of the planet. At its thickest, under mountain ranges, the crust is about 200 kilometers (or 125 miles) thick. By comparing rock samples dredged from the ocean floor with those on the continents, scientists can differentiate between two different types of crust. *Continental crust* is composed of light-colored rock (such as granite) consisting mainly of lightweight elements like aluminum, silicon, and oxygen (table 1). *Oceanic crust* is thinner than continental crust, but it's composed of denser rock types, such as basalt-containing iron and magnesium, as well as lightweight elements like silicon and oxygen. Because of density variations, the less-dense continental crust "floats" higher on the underlying mantle than the oceanic crust. As previously noted, Earth's crust is broken (like a cracked eggshell) into distinct interlocking segments called *plates*. Observing the cracked shell of a hard-boiled egg can help students imagine Earth's crust "cracked" into a number of different pieces, or plates.

Table 1. Differences between continental crust and oceanic crust

Continental Crust	Oceanic Crust
Light, less-dense rock, such as granite, containing these elements: • Aluminum • Silicon • Oxygen	Dark, dense rock, such as basalt, containing these elements: • Iron • Magnesium • Silicon • Oxygen

STOP AND THINK

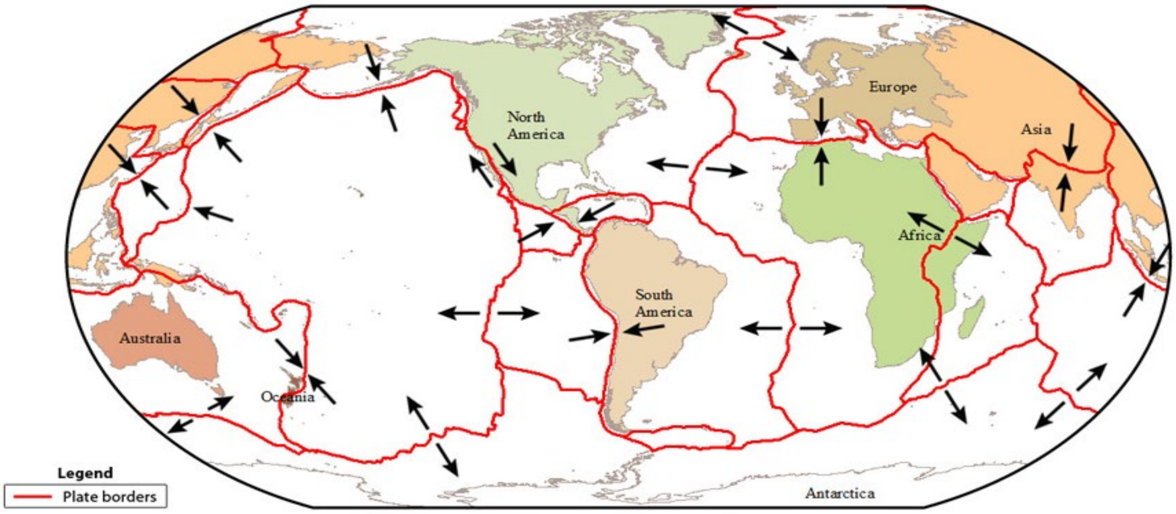
Why do continents (including the underlying crust) float higher on Earth's mantle than oceanic crust?

Underneath Earth's crust is the mantle. Scientists believe this layer consists of the same material that forms the crust but is hotter and denser than the crust because both the temperature and pressure inside Earth increase at greater depths. The crustal plates move across a portion of the mantle that flows very slowly, almost like a thick liquid. Imagine watching some cooked oatmeal, honey, or molasses ooze slowly down an inclined slope. That would resemble the flow occurring in the mantle that pushes and pulls the plates of Earth's crust, causing them to slowly move across the surface.

But how and why does the mantle move? Deep within Earth is the core—a mass of very hot, heavy metal (mostly iron and nickel) that sank, due to gravity, after Earth formed. Scientists believe that the heat from this metal triggers convection currents in the mantle. As Earth's core heats this already hot mantel material, it slowly rises toward the cooler surface (the crust), where it cools off and starts sinking back toward Earth's core. Differences in the density of hotter and cooler material in the mantle cause it to move continually.

What does the inside of Earth have to do with changes on the surface? Everything! A great amount of geologic activity occurs where tectonic plates interact—at the boundaries between plates. These plate interactions shape Earth's surface, resulting in earthquakes and volcanoes, as well as the uplift of mountains. There are three possible boundaries between plates:

1. **Divergent boundaries.** On the following map (figure 7), find a place where arrows on either side of a plate boundary are pointing in opposite (or nearly opposite) directions. Where plates move apart, or diverge, *magma* (hot, molten rock from inside Earth) oozes through cracks between the plates.[1] The magma then hardens to create new, solid crust. Over time, this building up creates underwater mountain ridges. Divergent boundaries mostly occur deep under oceans along a long, continuous underwater mountain range called a *midocean ridge*. Midocean ridges occur in all of the world's major oceans.



Courtesy of BSCS

Figure 7. Earth's major tectonic plates

Sometimes plates pull apart under continents rather than under oceans. This creates long valleys called *rift valleys*. Rift valleys are often associated with volcanic activity when

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[1] When magma reaches Earth's surface, it's called *lava*.

hot lava emerges through cracks in the crust, or geysers and hot springs indicate that magma is close to the surface. Continental rift valleys can grow wider as the crustal plates pull apart. They can also become deeper, causing the land surface to drop below sea level. When a rift valley meets the ocean, ocean water can submerge the valley floor. An example of a continental rift is the famous East African Rift, where a large fragment of continental Africa is being torn away to the east. You may have noticed in figure 7 that no plate boundary is marked through this “rifting” section of Africa, yet scientists believe that the eastern portion of Africa will one day break away from the rest of the continent, much like the Arabian Peninsula has pulled away from northern Africa, creating the ever-widening Red Sea.

STOP AND THINK

Are North America and Europe moving away from or toward each other?
Is the Atlantic Ocean getting wider or narrower?

2. **Convergent boundaries.** When two plates carrying continents collide, the leading edges of both plates crumple to create lofty mountain ranges over a period of millions of years (figure 8). To help students visualize two land masses colliding, teachers often use wet graham crackers or the analogy of trains colliding on the same track. The tallest mountains in the world today, the Himalayas, were formed when the plate carrying India collided with the plate carrying Eurasia. Evidence indicates that this type of collision has occurred many times throughout Earth’s history, resulting in ancient mountain ranges like the Appalachians in North America and the Ural Mountains of Russia.

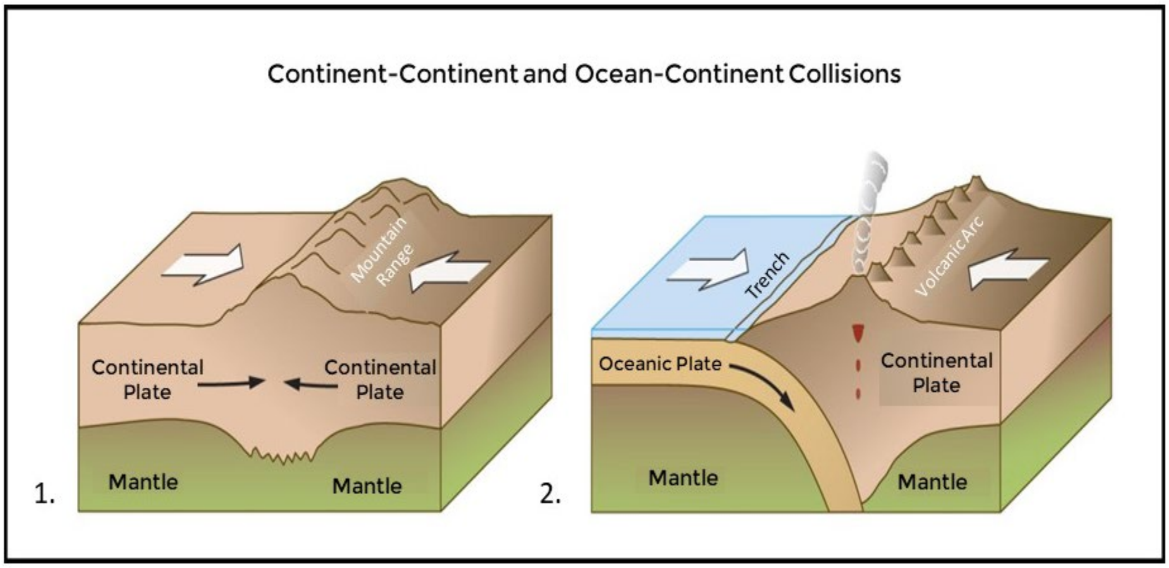

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Figure 8. Two types of plate collisions: (1) Two continental plates collide, forming nonvolcanic mountains, and (2) a continental plate and an oceanic plate collide, forming a deep ocean trench and a line of volcanoes

At other times, tectonic plates carrying dense oceanic crust collide with plates carrying less-dense continental material. These are also convergent zones, since plates are crashing together, but because oceanic crust is denser than the continental crust, it sinks beneath the continental plate. The sinking oceanic crust is destroyed as it's pushed into Earth's mantle, and the crustal material eventually melts. This type of plate collision is known as a *subduction zone*. Two important surface features form where the oceanic crust sinks into the mantle: Deep trenches on the ocean floor indicate where ocean crust is sinking, and sometimes lines of volcanoes form above subduction zones. For example, a deep trench and line of volcanoes are found where the Juan de Fuca Plate sinks beneath the North American Plate, creating active volcanoes like Mount St. Helens, Mount Rainier, Mount Baker, Mount Hood, and Mount Shasta in Washington, Oregon, and Northern California (figure 9).

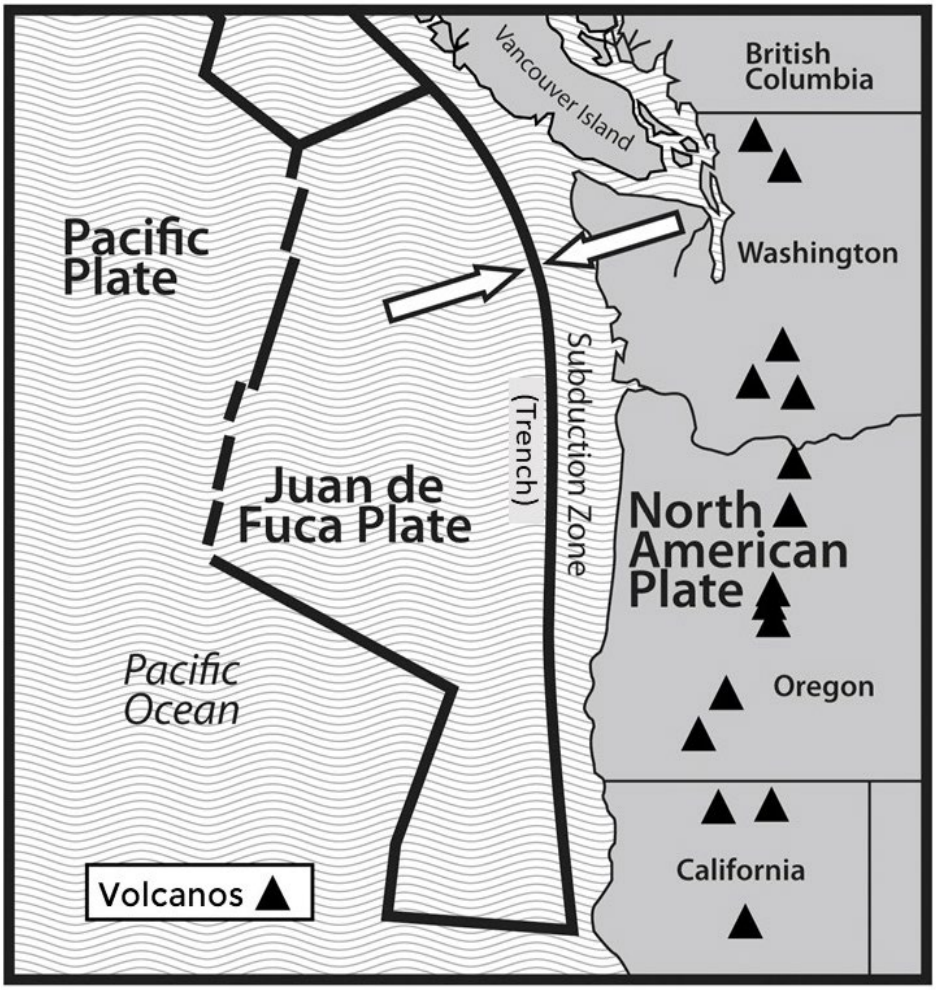

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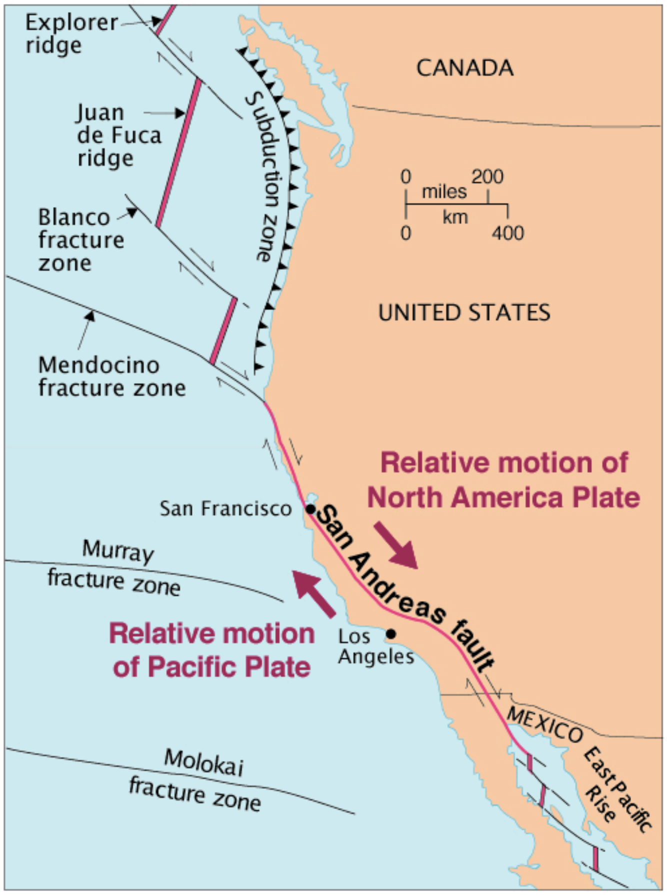
Figure 9. The oceanic Juan de Fuca Plate sinks under the continental North American Plate, where the two plates collide. Note the deep trench off the coast and a line of volcanoes where the melted crustal material erupts on the surface.

3. **Transform plate boundaries.** How do tectonic plates interact when they aren't crashing together or pulling apart? Parking lots offer a clue. Have you ever seen a car try to squeeze into a space that's too small? The result could be a dramatic screeching and grinding as one car scrapes past the other.

   Tectonic plates do the same thing. The surface where the two plates grind past each other is called a *transform plate boundary*, or a *transform fault*. Faults are cracks in Earth's crust where movement occurs. These cracks can be as large as plate boundaries or smaller cracks within a plate. The movement in a transform fault is side to side rather than up or down. This kind of movement would create higher places and lower places. Transform plate boundaries are often associated with strong, frequent earthquakes. Perhaps the best-known transform fault between two plates is in California. There the San Andreas Fault (figure 10) marks the boundary where the Pacific Plate is grinding its way northwest along the edge of the North American Plate. At times, imperceptibly slow movement occurs along the plate boundary. But at other times, the plates get stuck, building up pressure between them until that pressure is suddenly released, causing an earthquake. A lurch along the San Andreas Fault caused the massive 1906 earthquake in San Francisco, as well as the Loma Prieta earthquake in the San Francisco Bay area in 1989 and the Northridge earthquake that shook the Los Angeles area in 1994.



Courtesy of USGS

Figure 10. The San Andreas Fault

6. Earth Builds Up

Colliding, or convergent, plate boundaries result in mountain building on Earth's continents. Mountain building can occur where plates collide to form nonvolcanic mountains like the Himalayas at the site of continent-to-continent plate collision, or volcanic mountains at the site of oceanic-to-continental plate collision at subduction zones. We've also seen that plate collisions in Earth's ancient past may have formed older mountain ranges that are far from plate boundaries today. (One example is the Appalachian Mountains in the eastern United States.)

The vast majority of earthquakes and volcanic eruptions occur near plate boundaries, but there are some exceptions. For example, the Hawaiian Islands, which were built entirely from volcanic eruptions, formed in the middle of the Pacific Ocean more than 3,200 kilometers from the nearest plate boundary. How do the Hawaiian Islands and other volcanoes that form in the interior of plates fit into the plate-tectonics picture? Scientists theorize that certain places in Earth's mantle are exceptionally hot; so hot, in fact, that magma melts through the crust. We call those places *hotspots*. As the crustal plate moves over a hotspot—like your groceries moving along a conveyor belt at the checkout line—volcanoes located over the hotspot become active, and those no longer over the hotspot become dormant. This creates long chains of dormant volcanoes next to a single currently active volcano (figure 11).

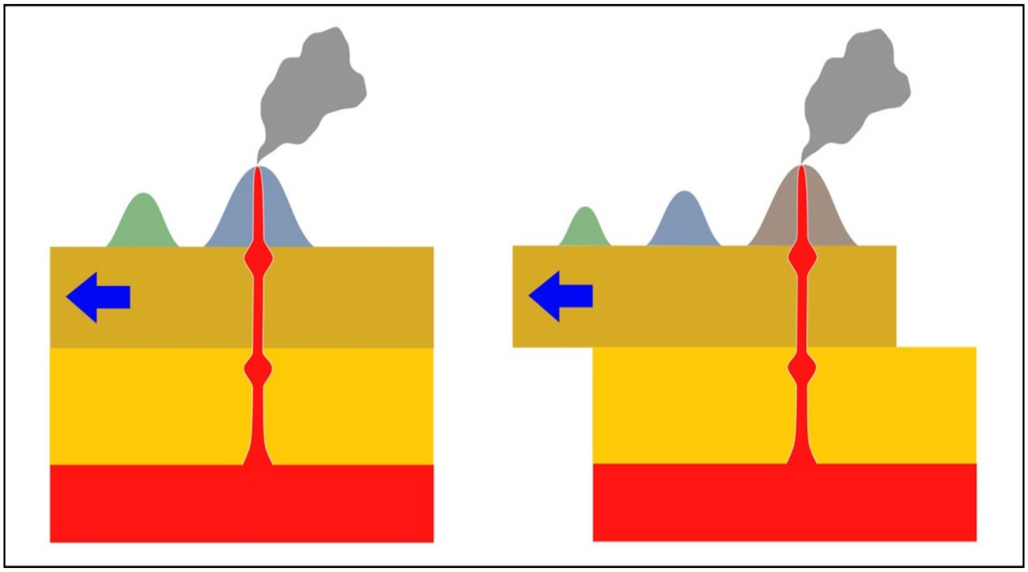

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Figure 11. A crustal plate moves over a hotspot in Earth's mantle

The positions of dormant volcanoes trace the movement of a plate over a hotspot. Look at the Hawaiian Islands in figure 12. Each island originally formed as an active volcano, but only the southeastern-most island has active volcanoes today. The active geysers and hot springs at Yellowstone National Park in Montana and Wyoming are evidence of another hotspot sitting under the North American Plate.

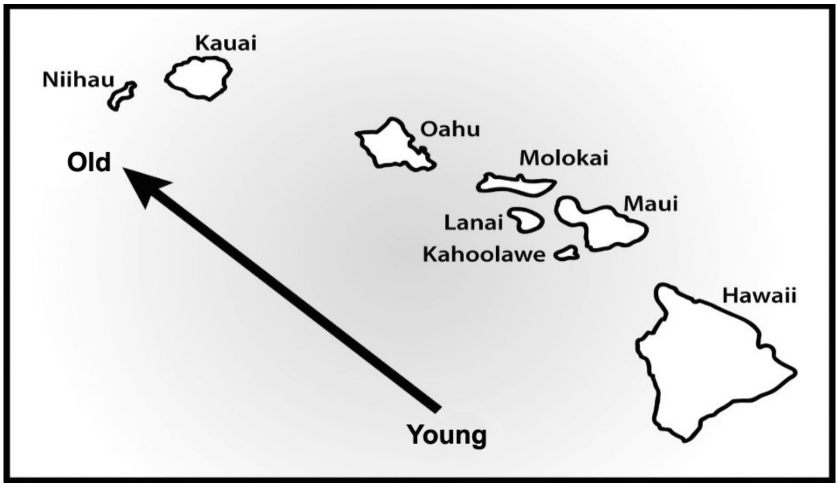

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Figure 12. The Hawaiian Islands formed over a hotspot.

But what about the expansive mountain ranges in the western United States—the Rockies and the Sierra Nevada? For the most part, they aren't volcanic, which means they weren't caused by moving over a hotspot, nor are they the result of continental collisions at a plate boundary or subduction at the edge of the North American Plate. How can plate tectonics explain the existence of these mountains? As plates collide, certain things happen at the edges (crumpling or subduction), but areas not at the edge can also push up or scrunch down. Imagine a sudden, violent car collision. The solid metal bends and breaks not just at the point of the collision but also on the hood and sometimes even in the passenger compartment. It's harder to imagine that happening slowly rather than suddenly with large swaths of solid rock, but the slow-moving forces pushing and pulling the plates can fold, bend, and break large blocks of rock within a plate, lifting up segments of the crust, increasing elevation, and exposing long-buried rock surfaces. It makes sense that these areas of deformation and surface buildup are only on the western side of the North American continent, since this is the side slowly colliding with the Pacific Plate, and these mountain ranges are the ripple effect of that collision.

Earth's crustal plates move at different rates. In some places, like the South Pacific, plates move as much as 12 centimeters per year. In other places, plate movement occurs much more slowly, only 1 or 2 centimeters per year. Generally we teach students that tectonic plates move slower than the rate of their growing fingernails. This slow movement can cause some very fast changes on Earth's surface, such as the jolts that occur during earthquakes or the eruption of a volcano. Other changes happen very slowly and imperceptibly, such as the uplift of mountains.

7. Earth Wears Down

At the beginning of this document, we mentioned that Earth is dynamic. We've just illustrated the dynamic nature of Earth's crust as plates collide, uplifting mountain ranges and forming chains of volcanoes. But do mountains continue to grow forever? Will they eventually grow so tall that they reach beyond Earth's atmosphere?

The answer is no. Just as forces build up Earth's surface, other forces are wearing it down. Heat from Earth's core supplies the energy to create plate movement that builds mountains, and energy from the Sun is responsible for tearing down Earth's surface. Does that surprise you? It's easy to see that the Sun's energy warms and lights the planet, but how can it tear down giant mountain ranges? To understand this, recall that the Sun's energy creates the water cycle—the continuous process of evaporation, condensation, and precipitation—that occurs in Earth's atmosphere and also drives wind and temperature changes. When rock materials are exposed to the Sun, water, and wind, they break down and wear away. This process is called *weathering*.

Some types of weathering involve only changes in size in which bigger pieces are broken into smaller pieces. This kind of weathering, called *physical weathering*, is easily seen at the base of a rocky cliff. The broken pieces of rock are just smaller pieces of the cliff itself.

Sometimes temperature fluctuations cause physical weathering. During the hot summer, rock expands in response to high temperatures, and in the winter, it contracts in response to cold temperatures. Over many years, expanding and contracting cause the rock to weaken and break apart.

Other factors can cause physical weathering. Plant roots can grow in rock cracks, forcing the cracks to widen. Water can collect in cracks and then freeze in the winter. Since water expands when it freezes, it causes these small cracks to widen. (If you live in a climate that experiences freezing temperatures in the winter, you've likely seen evidence of this phenomenon in the form of potholes in street surfaces.) Eventually, rock pieces break off and fall to the ground in a process called *ice wedging*. Even falling rocks can hit other rocks and cause them to break.

When rock dissolves instead of breaking apart, it's called *chemical weathering*. This kind of weathering changes the type of material, not just its size. You've likely seen rust forming on a bicycle sitting outside. This is one example of chemical weathering. When iron combines with oxygen from the air, a new product forms: iron oxide (rust).

A similar type of chemical weathering happens to rocks. Your students may know that when they chip away at a rock, the outside is dull, but the inside is shiny or colorful. The exterior has been chemically weathered and has lost its shine and color because the minerals on the outside layer have changed into a new kind of matter.

Weathering shouldn't be confused with *erosion*. The term *weathering* refers to the breakdown of materials, whereas *erosion* refers to the transport of weathered particles from one place to another. Weathering (breakdown) nearly always precedes erosion (removal), so these processes most certainly relate to how Earth's surface is torn down, but they're distinctly different. In lessons on weathering, students will recreate natural weathering over a short class period (such as shaking rocks in a jug to make smaller rocks or sand), but it's important to clarify that weathering processes in nature usually occur over long periods of time, not in a couple of hours or even a couple of days.

Many students believe that earthquakes cause rocks to break apart, particularly along fault lines. While this is partially true, it's a mistake to think that earthquakes turn tall mountains into small mountains. Earthquakes that occur at convergent plate boundaries, like those near the Himalayan Mountains, can actually result in mountains growing taller, not smaller.

STOP AND THINK

The building up of Earth's surface takes place over a long period of time, but dramatic changes can also occur in relatively short amounts of time (e.g., changes caused by earthquakes or volcanoes). Consider the forces (weathering and erosion) that wear down Earth's surface. Can you think of examples where Earth's surface is torn down dramatically in a short amount of time?

8. The Downhill Movement of Earth Materials

We mentioned the important role of the Sun in powering the water and wind that contribute to weathering and erosion. But another important force is at work tearing down Earth's surface. That force is *gravity*.

Wind, water, and gravity all contribute to moving material from high places to low places on Earth. Rock fragments can be found at the base of most cliffs and hillsides. These fragments weathered and then broke off and fell to the ground. The movement, or transportation, of weathered pieces of rock from the cliff to the ground is an example of *erosion*. While weathering can cause changes in the size, shape, and composition of rocks, erosion changes their *location*.

Gravity is the underlying force behind all erosion. In its simplest form, it causes pieces of rock to move downhill. This form of erosion is most evident in landslides and rockslides. But gravity works in more complicated ways, too. Gravity causes water to run downhill and carry away pieces of rock and soil in its path. It causes glaciers to flow, carrying large boulders down a mountain valley. However, it's difficult for 4th-grade students to grasp a force as abstract as gravity, so lessons will focus on water—in the form of streams and rivers —as the main mover of Earth materials from high places to low places.

The purpose of using stream tables in the lessons is for students to get a sense of how water can move materials. Geologists use some basic terms to describe streams and rivers and the erosion they cause. The origin of a stream (where it begins) is called the *source*, and the place where a river flows into a larger body of water is called a *mouth*. When streams come together, they form *rivers*. The bottom of a river or stream channel is called the *bed*, and its sides are called the *banks*.

A stream table (figure 13) is a classic tool earth scientists use to study the processes of stream formation. Physical models like this are valuable in helping scientists explore and test their ideas about processes that are difficult to observe in the field. As valuable as a stream table is, however, it isn't a perfect representation. For one thing, the scale is very different from that of a real stream and can offer only a rough approximation of stream formation. Even so, stream tables provide a wonderful hands-on exploration of stream processes that are hard to see in real life. In a lesson using stream tables, you might be tempted to conduct a demonstration rather than having your students work with the materials. The mess of the stream-table exploration can seem overwhelming to a teacher in a clean, dry classroom, but we encourage you to take the appropriate precautions and go with the flow! The advantage of having students work with the models and experience the variations in erosion is well worth the effort. If you plan ahead and

Photo courtesy of BSCS

Figure 13. Stream-table setup

make arrangements with the custodian for disposing of the water and sediment, you should have very few problems. Provide an extra bucket or two of water for students to rinse their hands. That way they won't rinse their sandy hands in the sink and potentially clog the drain.

Rivers have different shapes depending on the amount of erosion occurring in the river channel. Whenever there is a large difference in elevation from one point to another—a steep slope, in other words—the water flow is usually swift, and the river cuts through the channel, carrying with it small pieces of dirt, sand, and pebbles, as well as larger bits of rock. When a river passes through a landscape that has less of a slope, water flows more slowly, and the cutting action slows or stops altogether. Instead, the water erodes the banks, widening the river and smoothing over the waterfalls. When the slope of the river channel becomes almost level, water moves very slowly. It no longer carries larger rocks and pebbles but continues to carry away smaller materials along its banks. Rivers constantly deposit rocks and soil and re-erode the soil and rocks over which they flow, depending on the speed of the water and the changes in elevation over their course. All things being equal, a faster-flowing stream or river will carry a greater load of material (figure 14).

Photo courtesy of Corel

Photo courtesy of Corel

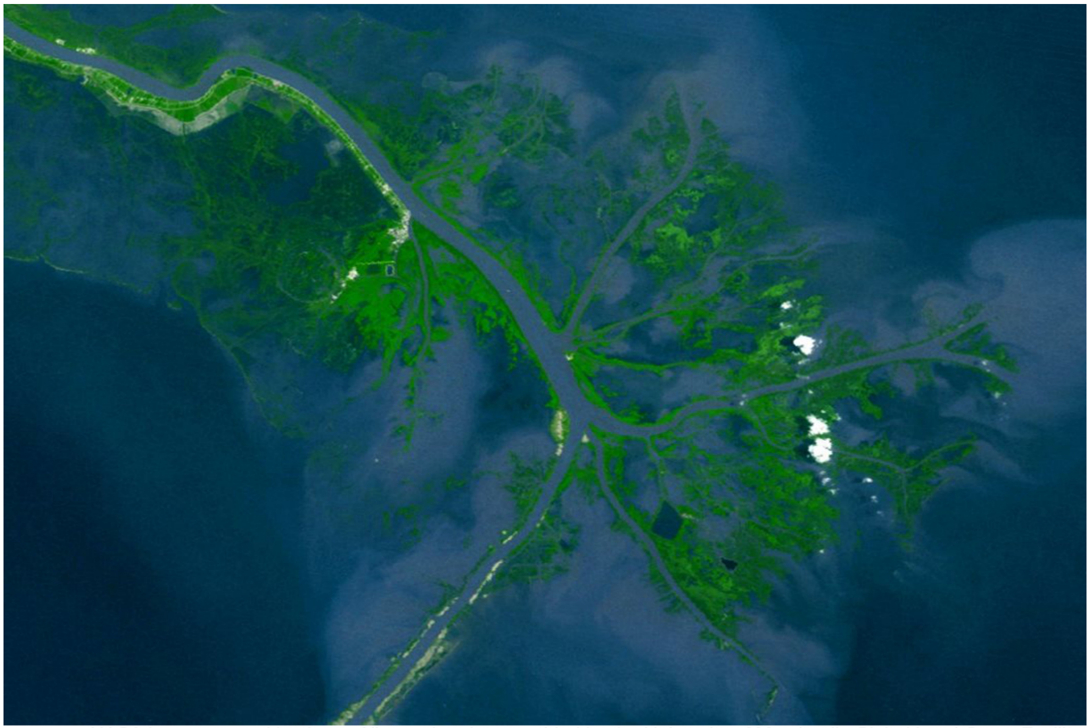
Figure 14. Fast-flowing rivers erode more material and are capable of carrying larger pieces of sediment, such as rocks. As the slope decreases, rivers slow and deposit larger sediments, carrying only finer-grained sand, dirt, or silt to their mouths.

The erosive ability of a stream or river can be measured in two ways: (1) *competence*, determined by the size of the largest particle that a stream or river can move, and (2) *capacity*, the total amount of sediment that a stream or river can carry. Competence is directly related to the slope of the land and the velocity of the water, whereas capacity is directly related to the amount of water flowing through a stream or river.

Rivers empty into lakes, other rivers, or oceans. The sediments that remain suspended in the water at journey's end are dropped at the mouth of a river. This happens because the velocity of the water decreases when the river flows into a slower or standing body of water. As the soil and rock deposits build up at the mouth of a river, a *delta* forms. The delta of the Mississippi River is well known, reaching far into the Gulf of Mexico (figures 15 and 16).

Figure 15. The Mississippi River delta

National Park Service, nps.gov



NASA image created by Jesse Allen, using data provided by the University of Maryland's Global Land Cover Facility.

Courtesy of Jesse Allen, NASA

Figure 16. The Mississippi River carries material from the eastern slope of the Rockies, the western slope of the Appalachians, and the area in between to the Gulf of Mexico, where the deposits have formed a vast delta.

To apply our understanding of the role of weathering and erosion in tearing down Earth's surface, visualize materials being carried from high places and deposited in low places and eventually ending up in the lowest places on the planet—oceans. Flowing rivers create landforms, such as river valleys and canyons, including the Grand Canyon in America's Southwest. The weathering and erosional forces of wind and water have created interesting rock shapes at Garden of the Gods in Colorado, as well as Arches, Zion, and Bryce Canyon National Parks in Utah (figure 17).

STOP AND THINK

How does the combination of weathering and erosion lead to the flattening of Earth's high places?

Photograph by Ahodges7, Wikimedia

Photo courtesy of Pixabay.com

Photo courtesy of Roger Sylvia, Wikimedia

Photo courtesy of Ron Clausen, Wikimedia

Figure 17. Clockwise from top left: Rock formations at Garden of the Gods Park, Colorado; Zion National Park, Utah; Arches National Park, Utah; and Bryce Canyon National Park, Utah

Without differences in elevation that make up Earth's surface, water would have no place to go. Water flows downhill. A *divide* is a high place in the land. Streams on one side of the divide flow in the opposite direction of streams on the other side. These streams may then flow into different oceans. For example, rivers on the eastern side of the Continental Divide in the Rocky Mountains flow east and end up in the Mississippi River delta, while rivers on the western side of the Continental Divide flow west to the Pacific Ocean. Following the paths of streams and rivers from divides through valleys and eventually to oceans enables students to see the ways that weathering and erosion tear down and move Earth's surface. Recognizing that these processes have occurred for millions, even billions, of years helps students imagine how low and rolling mountains like the Appalachians may have once been as tall and jagged as the Himalayas.

9. Putting It All Together—A Dynamic Earth

At this point we've seen that Earth is always changing. Some changes in Earth's surface are abrupt (such as earthquakes and volcanic eruptions), while others happen very slowly (such as plates uplifting and mountains wearing down). Whatever the speed of the change, the material that makes up Earth goes through a continuous cycle of uplifting and wearing down.

In lesson 7b of this unit, students look at a relief map of the United States and attempt to apply the concepts of plate movement, uplift, weathering, and erosion to explain the formation and wearing down of the San Gabriel Mountains in California. Don't expect that after only six lessons, students will be able to apply all the concepts correctly. Instead, look for evidence they understand that these processes can explain the formation and location of the landforms they see, even though their application of the concepts may not always match their scientific understanding.

STOP AND THINK

Challenge yourself to look at the same relief map of the US from lesson 7b and explain how various landforms were created and how they might change in the future.

Following are some points you might include in your analysis of the relief map:

- At any given point, Earth's surface is building up in some places and wearing down in others.
- Active volcanoes on the West Coast in Washington, Oregon, and Northern California indicate plate collision, where an ocean plate collided with and subducted under a continental plate, allowing the melted plate material to create a volcanic chain.
- The mountainous western half of the country, including the San Gabriel Mountains in California and the Rocky Mountains in Montana, Wyoming, and Colorado, are the nonvolcanic ripple effect of plate collision occurring off America's West Coast.
- Well-worn mountains like the Appalachians in the eastern United States indicate an ancient plate collision but also provide evidence of many years of erosion and weathering that have reduced the elevation of the mountains and rounded off the jagged edges.

- Streams and rivers carry material carved off mountaintops to lower elevations, and this material eventually ends up on the ocean floor. The delta at the mouth of the Mississippi River consists of material from the Rockies and the Appalachians, as well as material from the Great Plains, that eventually ends up in the Gulf of Mexico.

References

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