

Content Background

Earth's Changing Surface

Introduction

As we start 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 is likely that you know that 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, then rivers, and eventually deposit these sediments in river deltas. You might know something about weathering, the ways that the tallest mountains, boulders, and rocks get broken 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 gets pushed and pulled when 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 occur in certain places on Earth but not in others? Why active volcanoes ring the Pacific Ocean but that pattern is not around the edges of the Atlantic Ocean? And are you clear about why it is important for your students to know about the processes that cause the surface of Earth 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 is written to support and further your own 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 and carry away the tallest mountains until they are once again flat plains. The goal is for you to develop a conceptual understanding about these ideas so that you will be able to more effectively teach elementary students.

The content is written with you, the teacher, in mind. It presents subject-matter knowledge that is tied closely to the model lessons you will be teaching. It also includes content beyond the model lessons so that you have a more complete understanding of the ways in which our planet is changing. There is additional content related to plate tectonics included here that has shifted to a higher grade level in the NGSS. We have chosen to leave it here in case you are responsible for higher grade levels. The background section "Earth Wears Down" is most closely related to the lesson set you will be teaching.

Getting Started: Dynamic Earth

The goal of this unit is for you and your students to see that Earth is always changing. Energy from deep inside the planet causes Earth's surface to move, and as a result towering mountains and striking 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, breaking down mountains into tiny grains of sand that are carried 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 (figure 1), but over long periods of time, by the forces of rain, wind, and gravity, they have become lowly vestiges of their once stately grandeur.



Photo courtesy of Partha Sarathi Sahana, Flickr



Photo courtesy of Ken Thomas, Wikimedia

Figure 1: Note the differences between the relatively younger Himalayan Mountains and the older, more eroded Appalachian Mountains.

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 other areas. The “stuff” (matter) that makes up the planet hasn’t changed; it is 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 this piece of matter and its possible journeys and changes 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. When the solar system was forming, 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 interior continues to seethe with hot, melted materials that roil and churn, resulting in dramatic changes seen on Earth’s surface.

There are two models for talking about the layers of Earth. The first model is more simplistic and often used to talk about the layers of Earth with students. It presents Earth as having a crust, mantle, and core (which is sometimes broken into the inner core and outer core). However, scientists use a more complex model to accurately represent the different layers of Earth. This model (figure 2) 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 into several major and minor plates that vary in density and move or “float on” the viscous layer of the asthenosphere. Convection currents and dissipation of heat from the mantle cause the movement of the plates.

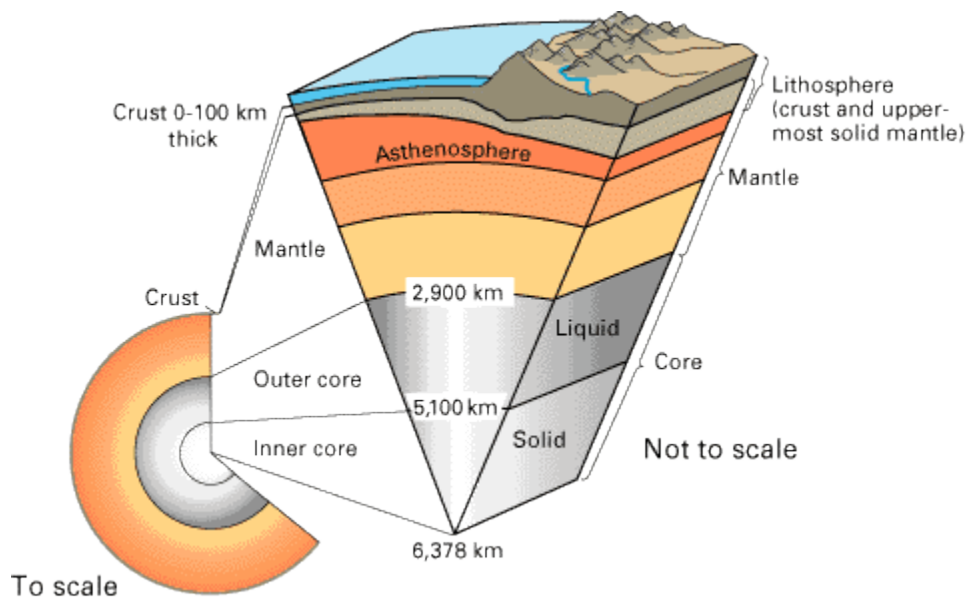


Figure 2: More complex model of Earth’s layers. (Adapted from USGS, copyright 1999, <http://pubs.usgs.gov/gip/dynamic/inside.html>)

Despite the different ways we talk about Earth’s layers, the big idea for students to understand is that Earth’s layers consist of different densities 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 is a very thin layer compared to the massive interior of Earth. Oceans ebb and flow over about 70% of Earth’s crust. Earth’s continents sit atop the remaining crustal area. The crust is broken into several large pieces that move slowly in response to the movement of the asthenosphere material below. Due to this constant motion, Earth’s surface has not always looked the way it does today. Continents and oceans have shifted—combining and separating in different configurations over Earth’s history. Occasionally, all the land masses have converged into one large supercontinent, which we call *Pangaea*, meaning “all land.” The most recent Pangaea broke apart about 200 million years ago, but vestiges of earlier continental collisions and separations indicate that this was not the first time that continents merged—and all that we know about Earth’s processes lead to the conclusion that it will not be the last.

Landforms

Let’s start by thinking about what we know about Earth’s surface. It is made up of many different types of landforms. A landform is a naturally occurring physical feature of the planet. We typically think of landforms describing parts of the terrain—or land—and also various kinds of water bodies. So, in defining landforms, we include descriptors like hills, ridges, cliffs, mountains valleys, plains, canyons, mesas, rivers, peninsulas, ponds, lakes, oceans, bays, deltas, and seas. Landforms do not include man-made features, such as canals, ports, and harbors, nor geographic features, such as deserts, forests, and grasslands. Landforms are categorized by characteristic physical attributes such as their shape, elevation, and slope.

Students tend to see landforms as permanent features of Earth. They assume that mountains and oceans have always been here and will always stay the same. An important goal of these lessons is to help students change this perspective and to view landforms as constantly changing. This is a big conceptual shift for students to make, and it will not 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” for the many volcanic eruptions) or along the Indonesian Archipelago. The western half of the United States has tall, jagged mountains—some rising above 14,000 feet in elevation—with swiftly flowing rivers, but the eastern half of the country has shorter, more rolling mountain ranges and meandering river systems. The highest peak in the Appalachians is Mount Mitchell in North Carolina. It lies at an elevation of only 6,684 feet above sea level. These mountains in the eastern United States have geology strikingly similar to mountains in Scotland and Scandinavia. The distinct pattern represented in the position of mountains, valleys, and plains has led scientists to ask why certain landforms occur in certain places and not in others.

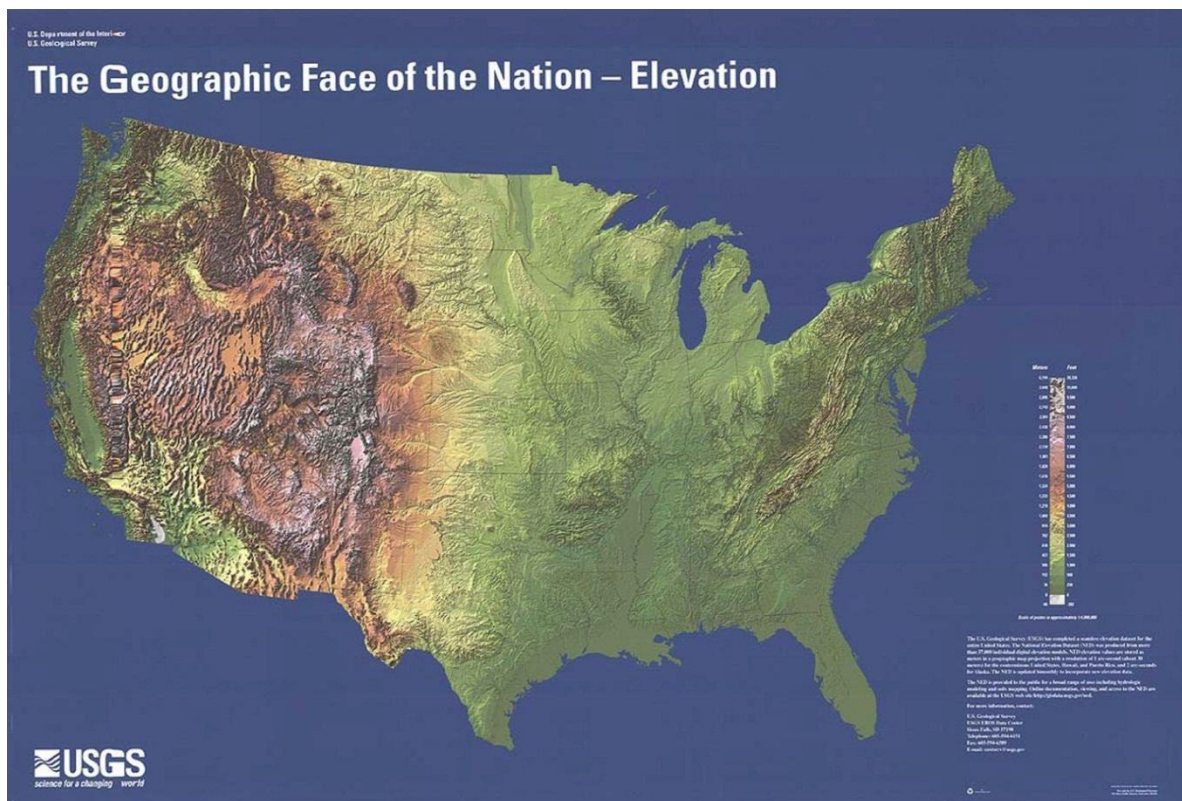
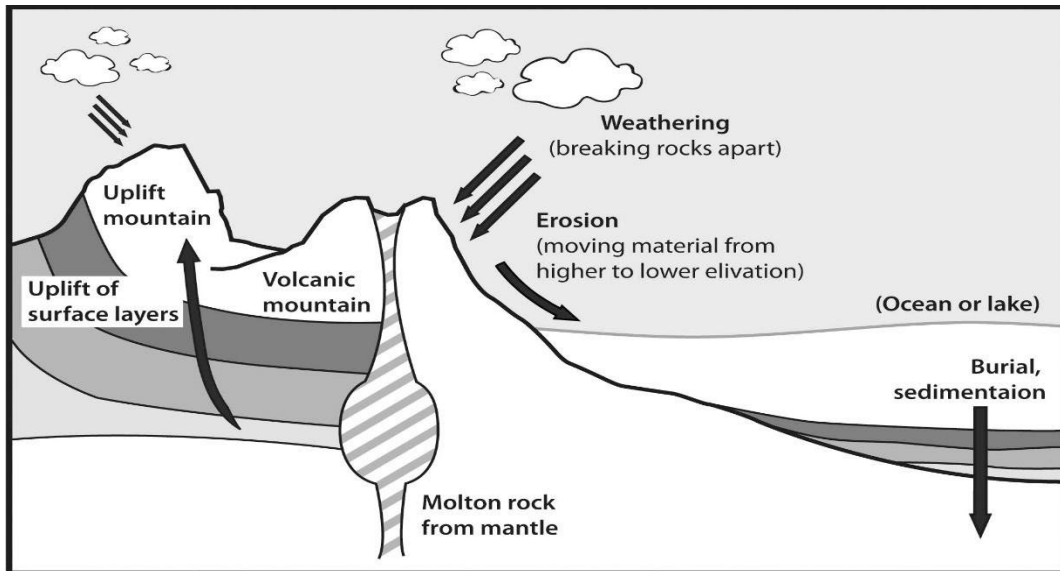


Figure 3: Topography of the United States.

STOP AND THINK: Why is Earth flat in some places and mountainous in others?

Understanding Earth’s Processes

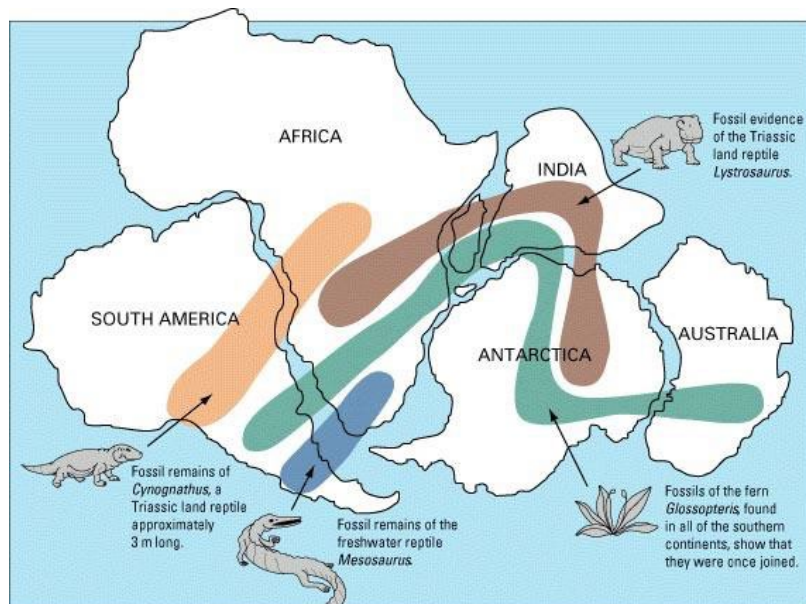
As early as the 1700s, Scottish naturalist James Hutton became convinced that the geological forces at work in his time—forces such as erosion and weathering that are barely noticeable to the human eye, yet immense in their impact—were the same as those that operated in Earth’s distant past. In this view, the same natural laws and processes that operate on Earth now have always operated in the past. This uniformitarianism philosophy included the concept that "the present is the key to the past" and that changes on Earth function at the same rates across time. Hutton used uniformitarianism to explain the geologic patterns seen on Earth. He described the landforms on Earth as being formed by 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. “The result, therefore, of this physical enquiry,” Hutton concluded, “is that we find no vestige of a beginning, no prospect of an end.”



Courtesy of Cal Poly Pomona

Figure 4: Processes that occur on Earth today are the same as those that have occurred throughout Earth's history.

Although uniformitarianism remains today as one of the fundamental principles of earth science, a huge breakthrough in our understanding of how landforms change occurred in the 20th century with Alfred Wegener's proposition that continents move. This was a radical idea that challenged our everyday perception that we are standing on solid, unmoving ground. Wegener noted that the shape 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 rock types matched up on Africa and South America as if they had at one time been continuous.



USGS. (1999). *Inside the Earth*. Retrieved from <http://pubs.usgs.gov/gip/dynamic/dynamic.html>

Figure 5: Similar fossils are found in Africa and South America.

Reasoning from these data, Wegener proposed that continents were not always where they are today but moved slowly over time. Unfortunately, during Wegener's lifetime, his theory gained little acceptance. It was only in the 1940s through the 1960s with the advent of new technologies allowing scientists to gather data about the ocean floor 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 today we recognize as places where large sections of Earth's crust are being shoved apart as surfacing **magma** (hot, molten rock from inside Earth) cools to make new crust.¹ 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 more than the continents move. The continents sit atop massive, interlocking sections of Earth's crust that slowly move. These are referred to as *tectonic plates*. The word "tectonic" comes from a Latin word meaning "of a builder." This emphasizes the role that 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 observations, including locations of earthquakes, mountain ranges, and active volcanoes. The theory of plate tectonics explains most geologic features so well that geologists cannot envision any other way to explain features of Earth's surface. To begin to understand the movement of the puzzle-like pieces of Earth's crust, you first have to understand something about the forces occurring inside the planet.

Earth, Inside and Out

In general, Earth is divided into three main layers: a very thin outer *crust*, a thicker *mantle*, and a *core*. The crust is the only layer that geologists can study firsthand. So, geologists use indirect data, such as the path of earthquake waves as they travel through Earth's interior, to make inferences about the interactions of the mantle and the core.

The outermost layer of Earth—the layer we walk on—is a thin, rocky skin that covers the planet. A good analogy is to think of a postage stamp stuck on a billiard ball. Earth's crust is very thin in relation to the rest of Earth. 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 often granite, a rock type that is composed mainly of lightweight elements like aluminum, silicon, and oxygen. Oceanic crust is thinner but composed of rock types that are denser, such as basalt containing iron, magnesium, silicon, and oxygen. Because of the difference in densities, the less-dense continental crust "floats" higher on the underlying mantle than does the oceanic crust. This crust is broken (like a cracked eggshell) into distinct

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

interlocking segments called *plates*. Students’ observations of the cracked shell of a hardboiled egg can help them imagine Earth being “cracked” into a number of different pieces, or plates.

| Continental crust | Oceanic crust |
|--|--|
| Light-colored, less-dense rock such as granite containing aluminum silicon oxygen | Dark-colored, dense rock such as basalt containing iron magnesium silicon oxygen |

STOP AND THINK: Why are continents (including the crust that underlies them) higher than the crust under the oceans?

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

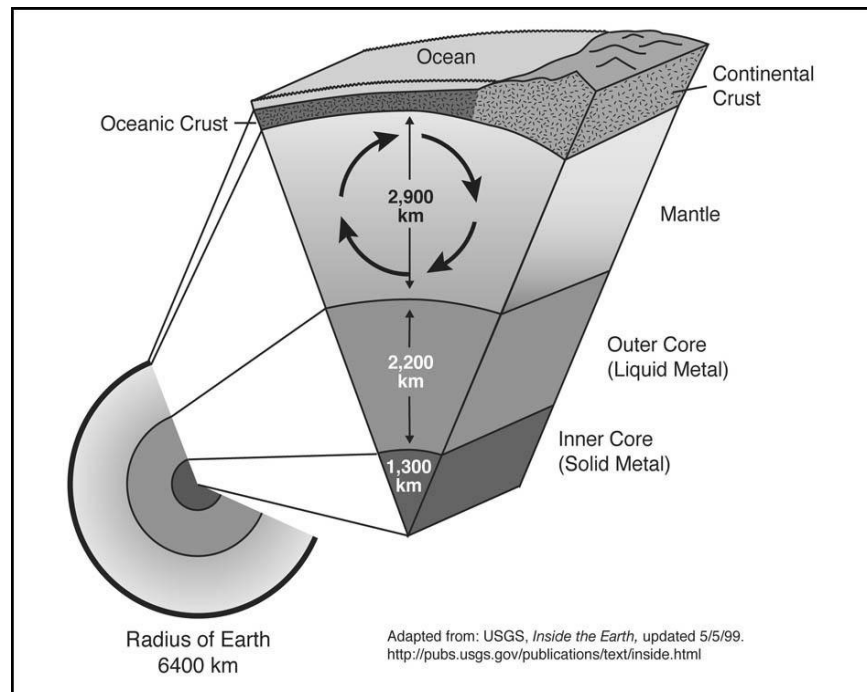


Figure 6: Earth’s interior.

But how and why does the mantle move? Deep within Earth is the core—a mass of hot, heavy metal (mostly iron and nickel). The core is very hot, and scientists believe that this heat triggers

convection currents in the mantle. Mantle material heated by Earth's core slowly rises. As the heated mantle material gets further from the heat source and closer to the surface (crust), it cools off and starts sinking back toward Earth's core. This can drag, or pull, the crustal plates. Differences in the density of hotter and cooler material in the mantle create a constant movement within the mantle.

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 the uplift of mountains as well as earthquakes and volcanoes.

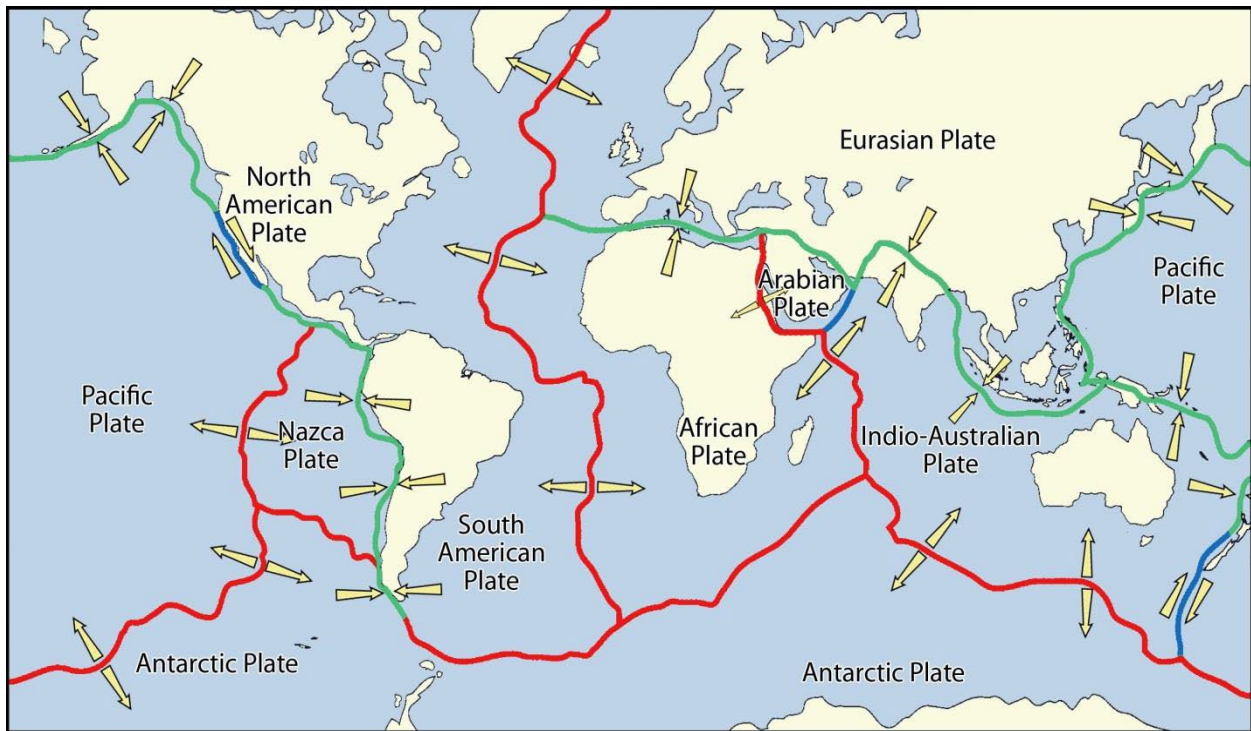


Figure 7: Earth's major tectonic plates.

There are three possible types of boundaries between plates:

- 1. Divergent boundaries:** In the map above, find a place where arrows on either side of a plate boundary are pointing in opposite (or nearly opposite) directions. Where plates move apart from each other, or diverge, magma oozes through the cracks that are left between the plates. The magma then hardens to create new solid crust. Over time, this building up has created underwater mountain ridges. Mostly, divergent boundaries occur deep under oceans, along a long, continuous underwater mountain range called a *mid-ocean ridge*. Mid-ocean ridges occur in all the world's major oceans.

STOP AND THINK: Are North America and Europe moving away from or towards each other? Is the Atlantic Ocean getting wider or narrower?

Sometimes, plates pull apart under continents rather than under oceans. When this occurs, the continents are pulled apart, creating long valleys called *rift valleys*. Rift valleys are often associated with volcanic activity when hot lava emerges through cracks in the crust, or geysers and hot springs provide indications that magma is close to the surface. Continental rift valleys can grow wider as the crustal plates pull apart. They also can get deeper so that the land surface is below sea level. When these rift valleys meet the ocean, ocean water can submerge the floor of the rift valley. 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 on 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.

- 2. Convergent boundaries:** When continental plates collide, the leading edge of both plates crumples to create lofty mountain ranges over a period of millions of years. In classrooms, teachers often refer to colliding trains on the same track or car collisions to help students visualize what it might be like for two land masses to collide. The tallest mountains in the world today, the Himalayas, were formed when the plate carrying India collided with the plate carrying Eurasia. In fact, these plates are still colliding as evidenced by Mount Everest’s height increasing approximately 2 cm each year. There is evidence 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.

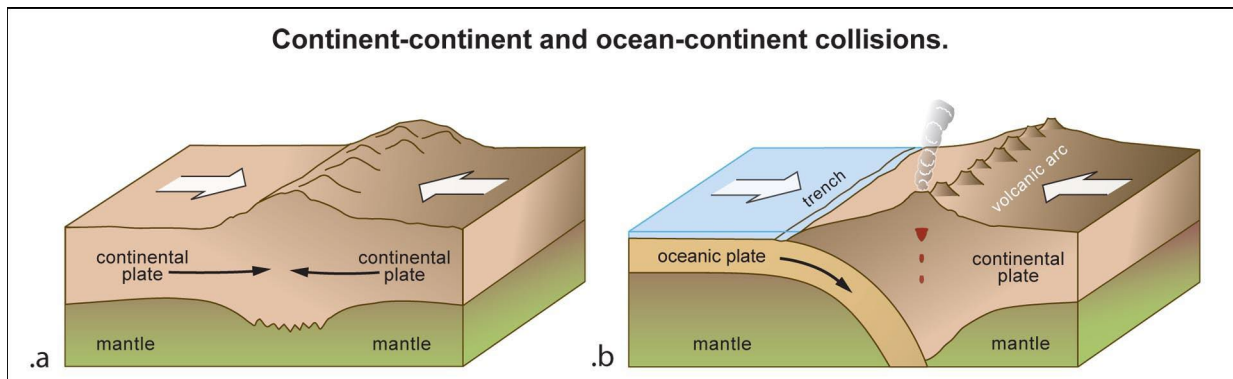
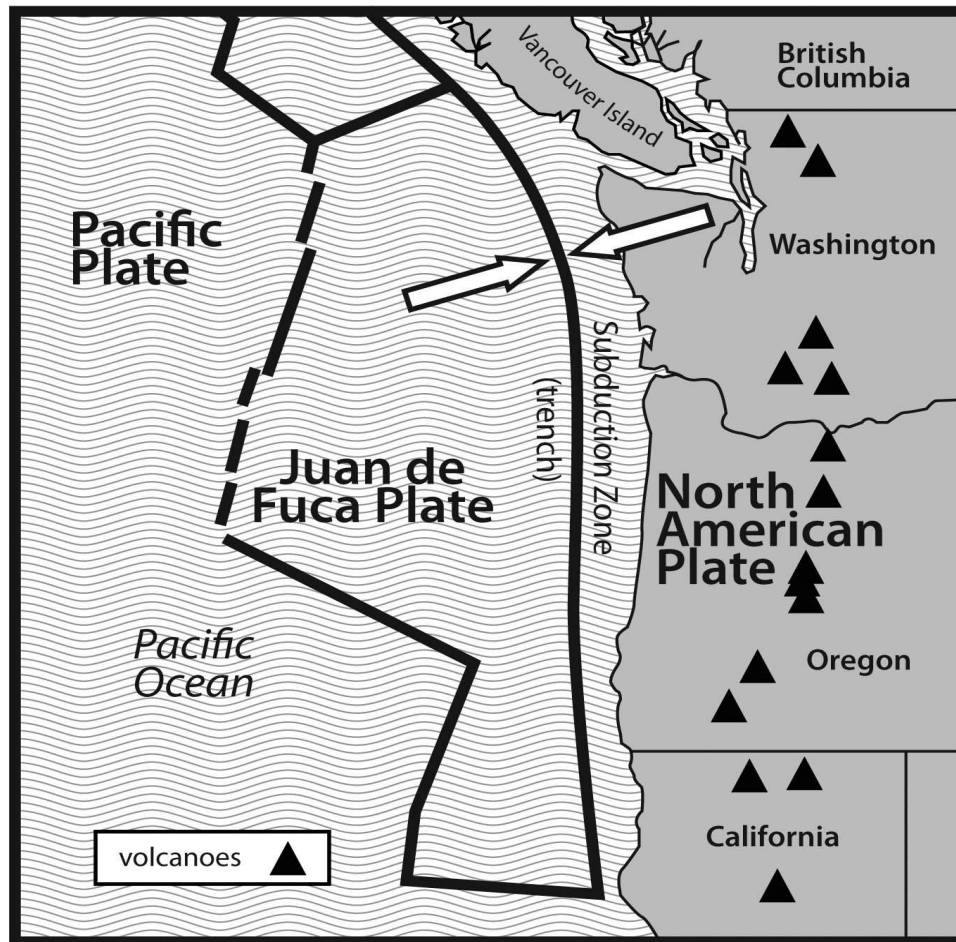


Figure 8: Two types of plate collisions: (a) two continental plates collide, forming nonvolcanic mountains and (b) a continental plate and an oceanic plate collide, forming a deep ocean trench and line of volcanoes.

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 is 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 oceanic crust sinks into the mantle: deep trenches on the ocean floor indicate where oceanic 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 such as Mounts St. Helens, Rainier, Baker, Hood, and Shasta in Washington, Oregon, and northern California.



Adapted from USGS. (1999). *This Dynamic Earth*. Retrieved from <http://pubs.usgs.gov/gip/dynamic/dynamic.html>

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 boundaries:** How do tectonic plates interact when they are not crashing together or pulling apart? Parking lots offer a clue. Have you ever seen a car try to squeeze into a space that is 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*—also known as a *transform fault*. Faults are

places where there's a crack in Earth's crust where movement occurs but no new crust is created. Faults can be as large as plate boundaries but can also describe smaller cracks within a plate. With a transform fault, the movement is side to side as plates move past each other. Transform plate boundaries are often associated with strong and frequent earthquakes. Perhaps the best known transform fault between two plates is in California. There, the San Andreas Fault marks 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, which can be released suddenly, causing an earthquake. A lurch along the San Andreas Fault caused the massive 1906 earthquake in San Francisco as well as the more recent Loma Prieta earthquake in the San Francisco Bay area in 1989 and the Northridge earthquake shaking the Los Angeles area in 1994.



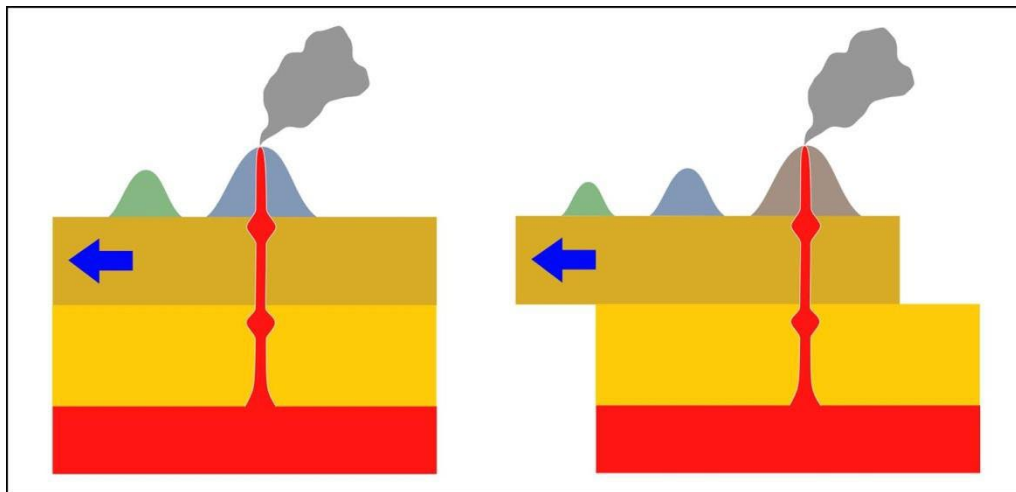
Figure 10: The San Andreas Fault.

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 a continental-to-continental plate collision or to form volcanic mountains at subduction zones of an oceanic-to-continental plate collision. We've also seen that older

mountain ranges that are far from plate boundaries today (like the Appalachian Mountains in the eastern United States) formed by plate collisions in Earth's very ancient past.

Most earthquakes and volcanic eruptions occur near plate boundaries, but there are some exceptions. For example, the Hawaiian Islands, which are built entirely from volcanic eruptions, formed in the middle of the Pacific Ocean more than 3,200 km (1,988 miles) 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 have described particular places in Earth's mantle that are exceptionally hot; so hot, in fact, that magma melts through the crust in these places. We call those places *hotspots*. As the crustal plate moves over the hotspot—like your groceries on the conveyor belt at the checkout line—volcanoes that are no longer positioned over the hotspot lose their heat and magma source and no longer erupt. This process creates a long chain of extinct volcanoes next to a single, currently active volcano (figure 11).



Wikipedia Commons

Figure 11: A crustal plate moves over a hot spot in the mantle.

The position of the dormant volcanoes traces the movement of the plate over the hot spot. Look at the Hawaiian Islands in figure 12. Each island was formed by an active volcano, but only the most southeastern island of Hawaii has active volcanoes today. The active geysers and hot springs in Yellowstone National Park in Montana and Wyoming are evidence of another hotspot sitting under the continental North American Plate. The southwest movement of this plate over 16 million years has resulted in seven extinct volcanic fields dotting southern Idaho and Oregon.

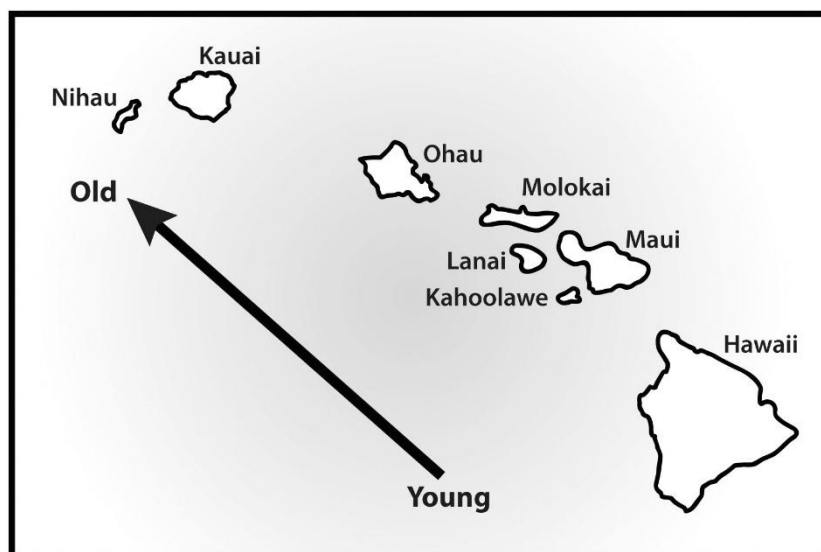


Figure 12: The Hawaiian Islands formed over a hot spot.

But how can the broad extent of mountains in the western United States—the Rockies—be explained? These mountains stretch over 3,000 miles from New Mexico to Alberta and British Columbia in Canada. Some segments of this chain are 300 miles wide. They are not the result of continental collisions or hot spots. For the most part, they are not volcanic, which means they are not the direct result of the subduction zone at the western edge of the North American Plate, but they are related. Roughly 70 million years ago, the oceanic plate being subducted under the North American Plate had a shift in its angle. Instead of being dragged deep into the mantle, this plate's more shallow movement scraped closer to the underside of the continental crust, causing an uplifting of the rock hundreds of miles from the convergence of the two plates. Similar to when a large spatula is used under a hot pizza or to get warm brownies out of a pan, this movement lifted up segments of the crust, increasing the elevation and exposing long-buried rock surfaces. Earth's crustal plates move at different rates. In some places, like the South Pacific, plates move as much as 12 cm (4.7 in.) per year. In other places, plate movement occurs much more slowly, only one or two centimeters per year. Generally, we teach students that plates move slower than the rate of their growing fingernail. This slow movement of plates can cause some very fast changes in Earth's surface, such as the jolt that occurs during earthquakes or the eruption of a volcano. Other changes happen very slowly and imperceptibly, such as the uplift of mountains.

Earth Wears Down

Do you remember at the outset of this document that we mentioned that Earth is dynamic? We've just seen 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 our atmosphere?

At the same time that forces are building up Earth's surface, there are forces wearing it down. Just as heat from Earth's core provides the energy to create the movement of plates for mountains to build up, 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, recall that it is the Sun's energy that 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 Sun, water, and wind, they break down and wear away. This is why the process of Earth's surface breaking apart is called *weathering*.

Some types of weathering involve only the changing of size from bigger pieces to smaller pieces of the same things. 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. In the winter, rock contracts in response to cold temperatures. Over many years, the expanding and contracting cause the rock to weaken and break.

Other factors can cause physical weathering. Plant roots can grow in cracks in rocks, forcing the cracks to widen. Water can collect in cracks and then freeze in the winter; because water expands when it freezes it causes small cracks to widen. (If you live in a climate that experiences freezing temperatures in the winter, you see 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*. Falling rocks can also hit other rocks and cause either rock to break.

When rock doesn't just break apart but dissolves, it is called *chemical weathering*. This kind of weathering changes the type of material, not just its size. You have seen the results of chemical weathering when you observe rust forming on a bicycle sitting outside. Rust forms when iron combines with oxygen from the air and makes a new product: iron oxide (rust). A similar type of weathering happens to many rocks. Your students may know that when they chip away at a rock, they see that the outside of the rock is dull, but the inside of the rock is shiny or colorful. The exterior has been chemically weathered and lost its shine and color because the minerals on the outside layer have chemically changed into a new kind of matter.

Weathering should not be confused with erosion. The term *weathering* refers to the breakdown of materials, whereas *erosion* refers to carrying away weathered pieces. Weathering (breakdown) nearly always precedes erosion (removal), and so they are most certainly related, but they are two distinctly different processes that both relate to how Earth's surface is torn down. Classroom lessons on weathering will have students recreating natural weathering over a class period (like shaking rocks in a jar to make smaller rocks or sand), but it is important to make clear that weathering processes in nature usually occur over long periods of time, not 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 is a mistake to think that earthquakes are what turn tall mountains into small mountains. Earthquakes that occur at convergent plate boundaries like those near the Himalayan Mountains actually can 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 there can also be dramatic changes that occur in relatively short amounts of time (earthquakes, volcanoes). Think about the forces that wear down Earth’s surface (weathering, erosion). Can you think of examples where Earth’s surface is torn down dramatically in a short amount of time?

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 there is another important force at work in the tearing down of Earth’s surface. That force is gravity.

Wind, water, and gravity all contribute to moving material from Earth’s high places to Earth’s low places. 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 of the weathered pieces of rock from the cliff to the ground is an example of erosion, or the transporting of weathered rock material. While weathering can cause changes in the size, shape, and composition of the rocks, erosion causes changes in the *location* of the rocks.

Gravity is the underlying force behind all erosion. In its simplest form, gravity 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 soil and rock in its path. Gravity 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 for our lessons, we 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 our lessons using stream tables is for students to get a sense of how water can move materials. You may find it useful to know some of the terms geologists use to describe streams and rivers and erosion caused by them. Where a stream starts is called the *source*, and the place at which 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 is a classic tool used by earth scientists to study the processes of stream formation. Physical models like this are valuable in helping scientists explore and test their ideas about things that are difficult to observe in the field. As valuable as a stream table is, it is not a perfect representation. For one thing, the scale is very different from that of a real stream. However rough the approximation, stream tables provide a wonderful hands-on exploration of stream processes that are hard to see in real life. In thinking about using the stream tables with your students, you might be tempted to do the lessons as demonstrations rather than involving the students 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 added effort. If you

plan ahead with the custodian about the disposal of the water and sediment, you should have very few problems. Provide an extra bucket or two of water in which students can rinse their hands. That way, they will not rinse their sandy hands in the sink and potentially clog the drain.

Rivers have different shapes depending on the amount of erosion that is occurring in the river channel. Whenever there is a large difference in elevation from one point to another and it has a steep slope—the water flow is usually swift and the river cuts through the channel, carrying with it small pieces, like dirt, sand, pebbles, and larger bits of rock. When a river passes through a landscape that has less of a slope, the water flows more slowly and the cutting action of the river becomes very slow or stops altogether. Instead, the river erodes the banks, widening the river and smoothing over the waterfalls. When the slope of the river channel becomes almost level, the water moves very slowly. It no longer carries the larger rocks and pebbles and continues to carry away only the smaller materials that are found along its banks. As rivers flow, they constantly deposit 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 13: Stream table setup.



Photos 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 mouth.

A river's erosive ability can be measured in two ways: *competence*, determined by the size of the largest particle that the stream or river can move, and *capacity*, the total amount of sediment that the stream or river can carry. A stream's competence is directly related to the slope of the land and the velocity of the water, whereas its capacity is directly related to the amount of water flowing through it.

Rivers empty into lakes, into other rivers, or into oceans. The sediments that remain suspended in the water at journey's end are dropped at the mouth of the river. This is because the kinetic energy of the water decreases at the mouth of the river. This means that either the water flow slows down or the amount of water (measured by its mass) decreases—or because both happen. More water that is moving faster can hold more sediment than less water moving slower. The deposits of this soil and rock build up at the mouth of the river and form a *delta*. The well-known delta of the Mississippi River reaches far into the Gulf of Mexico. Places with high tides have small deltas or none at all. Rather, they usually have estuaries where sediment moves back and forth and is held in place by plants.



National Park Service, nps.gov

Figure 15: The Mississippi River carries material from the eastern slope of the Rockies, the western slope of the Appalachians, and all the area in between to the Gulf of Mexico.

STOP AND THINK: How does the combination of weathering and erosion lead to the “flattening” of Earth’s high places?

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, the 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 the interesting rock shapes of the Garden of the Gods in Colorado as well as those of the Arches, Zion, and Bryce National Parks in Utah.



Figure 16: Clockwise from top left: Rock formations at Garden of the Gods Public 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. The streams on one side of the divide flow in the opposite direction of the 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 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 into oceans helps you to see 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.

Pulling It All Together—Dynamic Earth

At this point you have seen that Earth is always changing. Some changes in Earth’s surface are abrupt (such as earthquakes and volcanic eruptions), while other changes happen very slowly

(such as plate uplift and wearing down of mountains). Whatever the speed of the change, the material that makes up Earth is in a continuous cycle of building up and wearing down.

In Lesson 6 of this unit, students examine different landforms to apply the concepts of weathering, erosion, and deposition. Don't expect that after only five previous lessons that they will have it all right. You are looking for evidence that students understand that these processes can explain the formation and location of landforms they see, even if their application of the concepts does not always match the scientific understanding.

STOP AND THINK: Challenge yourself to consider other landforms in the United States and to explain how various landforms in the country were formed and how they might change in the future.

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

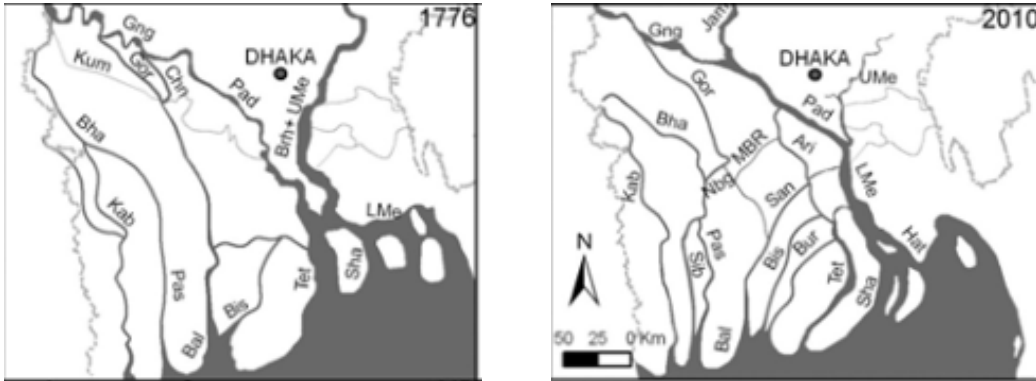
- At any given point, Earth's surface is building up in some places and wearing down in others.
- The processes above and below Earth's surface interact to keep matter cycling through Earth's systems.
- Active volcanoes on the far west coast of Washington, Oregon, and northern California indicate plate convergence where an ocean plate is being subducted under a continental plate, allowing the melted plate material to create a volcanic chain.
- The long and high spine of North America, the Rocky Mountains were the result of a subducting oceanic plate shifting to a shallower angle, scraping the underside of the continental plate, and causing massive uplift hundreds of miles from the plate boundary.
- Well-worn mountains, like the Appalachian Mountains in the eastern United States, are good examples of centuries of weathering and erosion reducing the elevation and once-jagged peaks of a mountain range formed during an ancient collision of tectonic plates.
- Material carved off mountain tops is carried to lower elevations by streams and rivers and eventually ends up in the ocean bottom. The delta at the mouth of the Mississippi River consists of material taken from both the Rockies and the Appalachians, as well as material carried by water from the Great Plains, to eventually end up in the Gulf of Mexico.

EARTH'S CHANGING SURFACE
PRETEST OR POSTTEST

Name _____

Date _____

1. The maps below show the Bengal delta in Bangladesh and India at different points in time.



Bengal delta in 1776 and 2010

Compare how the delta looked in 1776 with the way it looked in 2010.

a. What happened to the delta over this time period?

b. How did this happen?

2. Look at the photo of the mountains below. Will they always look this way?



Explain why you think the mountains will or will not change. Use drawings if that will help.

4. Look at the picture below.

People build dams across rivers. Dams solve problems for towns that are built near the river. Dams can also cause problems.



A dam on the Cetina river in Croatia

a. What problems do dams solve for people?

b. What problems do dams cause? How does this happen?

5. What do you know about the surface of Earth? What causes it to look the way it does?

Use pictures to describe what you know.

Explain your drawing.

Teacher name: _____

Circle one: PRE POST

Features Analysis Chart “Earth’s Changing Surface”

Describe the assessment item

Pre-posttest item #5

What do you know about the surface of Earth? What causes it to look the way it does? Use words and pictures to describe what you know.

Describe the ideal response

The picture should have water in it in the form of rain, rivers, and streams, and the water should be washing away soil and rock from the land and carrying it downstream. There might be mountains, canyons, or deltas as part of the picture. The picture should indicate weathering in some way, such as by rocks falling and breaking into smaller rocks, vegetation growing through rocks and splitting them apart, or water freezing in cracks in rocks and breaking them up. It may also show wind blowing soil and sand and creating dunes. The drawing may also show a dam as an example of how human activities change Earth’s surface.

Student responses to explain the drawing should include ideas such as the following:

I know that the surface of Earth is changing. Even though maps show land and water features, Earth’s surface has not always looked that way. For example, a delta can grow bigger over time as rock and soil move down the river and drops where the river meets the ocean. This is called erosion and deposition. Erosion and deposition are happening all over Earth’s surface and can cause Earth to look the way it does. Another process is weathering. Weathering is when water, wind, or plants cause rocks to break apart. These smaller pieces are then carried away (eroded) by wind, water, or gravity and deposited in a new location, changing the surface of Earth.

Humans can also change the surface of Earth. When we build dams and other structures along the river, we can change how fast rock is eroded and where rock and soil are deposited. This changes where the land builds up and can cause a delta to start shrinking. While weathering, erosion, and deposition are happening all the time, humans can change where and how fast they happen, which affects the surface of Earth.

| Features of a complete, accurate response | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | | | | | |
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| Earth’s surface changes over time. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Water causes the surface of Earth to change. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Water can pick up soil and rock and carry it downstream. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Water deposits the soil and rock in other places, such as where the river meets the ocean (a delta). | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Water (rain, waves, ice), wind, or plants can cause rocks to break apart. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Rain falling on the land can change the land by moving soil and rock. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Earth’s surface is building up in some places and wearing down in others at the same time. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Erosion and deposition are continuing natural processes that can change Earth’s surface quickly or slowly. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Humans can change how fast rock is eroded and where rock and soil are deposited. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

| Features consistent with misconceptions or problems | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | | | |
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| Earth's surface does not change. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Water is not strong enough to change the land by itself; something else causes the land to change (such as an earthquake cracking open the land). | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Land floats on top of water. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Only water flows through river systems (i.e., rock and soil are not moved by rivers). | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Water dissolves rock and soil and it disappears. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Water only changes the land during severe events, like floods. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Rocks, pebbles, and sand are not related to each other; i.e., each is stable and does not change form. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Other incorrect or unclear ideas | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
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