Main idea: The Earth’s surface is changing all the time. Weathering and erosion happen at a slow rate but over many years the results of these geologic processes produce big changes on the face of Earth.

We have a tendency to consider Earth as stable and never changing—mountains, lakes, even the positions of the continents. Actually our Earth is changing all the time, every hour of everyday.

**Slow and Quick Changes Shape the Earth**

You have learned that volcanic activity and earthquakes alter the landscape in a dramatic and often violent manner. Also you have learned that these happen quickly, although the forces that cause them may be building up for years before the actual “event” occurs. You have also learned how, on a much longer timescale (billions of years), the movement of Earth’s tectonic plates slowly reconfigures oceans and continents. Wind, water, and ice erode and shape the land in a much longer time scale as well. Small changes add up to big changes over time.

**Agents of Change**

Tectonic plates, driven by the convection currents in the asthenosphere, are ever so slowly pushing the continents as the seafloor spreads, and pulling the continents as heavy plates move under lighter ones. Volcanoes are erupting and spewing ash and lava. Wind is blowing sand, fine debris of rocks, consisting of small, loose grains, often of quartz, causing microscopic pieces of masonry buildings, bricks and stones to be etched away. Floods cause landslides, and move soil, to other areas.
The Beginning of Modern Geology

Geology is the science that deals with the dynamics and physical history of the earth, the rocks of which it is composed, and the physical, chemical, and biological changes that the earth has undergone and is undergoing. Prior to the late 1700’s scientists believed rocks were formed by the evaporation of minerals dissolved in sea water. This idea was about to be challenged, and disproved.

James Hutton

Born in Edinburgh, Scotland in 1726, James Hutton, was a physician, chemical manufacturer, farmer, naturalist and observer of the world. He studied medicine and chemistry at the Universities of Edinburgh and Paris. Then he spent fourteen years running two family farms. While running the farms, he began to wonder about the destructive forces of wind and weather he saw around him.

Leaving the farms to be run by the tenants, he returned to Edinburgh, in 1768, and began to devote his scientific knowledge and extraordinary powers of observation to the new science of geology. He wanted to explain the destruction he was observing. Because of his research and discoveries, James Hutton is known as the “father of modern geology”.

Hutton made carefully reasoned arguments to explain how the Earth’s processes work. He said the Earth is perpetually being torn down by one process and built up by another process. He called this the “great geologic cycle” and felt “the present is the key to the past”...in other words, the history of the Earth could be learned by understanding how processes (such as erosion and sedimentation) work today.

In a paper presented in 1788 before the Royal Society of Edinburgh, Hutton described one 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. (Does this remind you of the rock cycle?)
The fundamental force, theorized Hutton, heat from under the surface of the Earth. (Does this sound like the convection currents you have learned about?) He knew this internal heat existed because he knew there were hot springs and volcanoes which spew lava. From his observations of rock formations in Scotland, he inferred that high pressures and temperatures deep within the Earth caused the chemical reactions that created formations of different kinds of rocks like basalt and granite, and mineral veins.

**Uniformitarianism**

Another of Hutton’s key concepts was the *Theory of Uniformitarianism*. This states that the same geological forces at work today—barely noticeable to the human eye, yet immense in their impact—are the same as those that occurred in the past. This means that the rates at which processes such as erosion or sedimentation occur today are similar to past rates.

It became evident that large amounts of time would have been required for these slow processes to cause the effects visible on the Earth, such as worn down mountains, rocky shorelines and the Grand Canyon. Therefore, scientists of the time agreed that the Earth must be much older than the currently accepted idea of 6,000 years. This was the first revolutionary concept to emerge from the new science of geology!

Today, we understand that the Theory of Uniformitarianism is supported by a great deal of evidence, and accept it as true. We now know Earth to be 4.3 billion years old. We also know that great disasters such as earthquakes, asteroids, volcanoes, droughts and floods, are part of the regular cycle of the earth.

**The Shift in Thinking**

The effect that the idea of a more ancient, always changing planet had on the scientists who followed in the next century after Hutton, was profound! Charles Darwin, for example, was well acquainted with Hutton’s ideas, which provided a framework for the eons required by the biological evolution he observed in the fossil record.
Weathering

Weathering and Its Effects

Can you believe that tiny moss plants, a burrowing vole shrew, and even oxygen in the air can affect solid rock? These things and many more weaken and break apart rock at Earth’s surface. Together, surface processes that work to break down rock are called weathering. Weathering breaks rock into smaller and smaller pieces, such as sand, silt, and clay. These smaller, loose pieces are called sediment. The terms sand, silt, and clay are used to describe specific sizes of sediment. Sand grains are larger than silt, and silt is larger than clay.

Over millions of years, weathering has changed Earth’s surface. The process continues today. Weathering wears mountains down to hills. Rocks at the top of mountains are broken down by weathering, and the sediment is moved downhill by gravity, water, and ice. Weathering also produces strange rock formations like those shown at the beginning of this chapter. Two different types of weathering—mechanical weathering and chemical weathering—work together to shape Earth’s surface.

Mechanical Weathering

Mechanical weathering occurs when rocks are broken apart by physical processes. This means that the overall chemical makeup of the rock stays the same. Each fragment has characteristics similar to the original rock. Growing plants, burrowing animals, and expanding ice are some of the things that can mechanically weather rock. These physical processes produce enough force to break rocks into smaller pieces.
Water

Mechanical weathering, processes that cause physical disintegration of exposed rock without any change in the chemical composition of the rock. Water seeps into the cracks and crevices, if the water freezes, it expands. The ice then works as a wedge, called *frost wedging*. It slowly widens the cracks and splits the rock. When ice melts, water carries away (erosion) the tiny rock fragments lost in the split.

Temperature

*Exfoliation* is a repeated cycle during which rocks expand in daytime heat and contract at night, causing rocks to flake.

Salt

Salt also works to weather rock. Saltwater can get into cracks and pores of rock. If it evaporates, salt crystals are left behind. As the crystals grow, they put pressure on the rock, slowly breaking it apart.
Plants

The seed of a plant may sprout in soil that has collected in a cracked rock. As the roots grow, they widen the cracks. Eventually these roots break the rock into pieces. Over time, plants and trees can break apart even very large rocks Figure 5.

Even small plants, such as mosses, can enlarge tiny cracks as they grow.

Animals

Animals that tunnel underground Figure 6, such as gophers, moles, squirrels and prairie dogs, also work to break apart rock and soil.

Other animals digging on the surface and running and living on the surface break apart rock aboveground, causing rock to slowly crumble.

Abrasion

Tiny rock fragments carried by the wind and water (and even larger clasts carried by glaciers) wear down landforms by the process called abrasion. Sand, stones, pebbles (and in the case of glaciers, larger rocks and boulders) scrape across Earth’s surface, acting like sandpaper to polish or sometimes pit the surface.
Chemical Weathering

**Chemical weathering** is the breakdown of rocks caused by chemical reactions (chiefly with water and substances dissolved in it) rather than by mechanical processes. There are three main chemical reactions that decompose rocks: **acid reactions**, oxidation and **hydrolysis**.

**Acid reactions**

Sometimes, carbon dioxide from the air or soil mixes with water. This produces a weak acid, called carbonic acid that can dissolve rock. Carbonic acid is especially effective at dissolving limestone. When the carbonic acid seeps through limestone underground, it can open up huge cracks or hollow out vast networks of caves.

Sometimes, chemical weathering dissolves large regions of limestone or other rock on the surface of the Earth to form a landscape called **karst**. In these dramatic areas, the surface rock is pockmarked with holes, sinkholes, and caves. One of the world’s most spectacular examples of karst is the Stone Forest, near Kunming, China.

Pollutants, such as sulfur and nitrogen from fossil fuel burning, create sulfuric and nitric acid. Sulfuric and nitric acids are the two main components of **acid rain**, which accelerates chemical weathering (Figure 6). Acid rain is caused by sulfur and nitrous oxides mixing with water in the atmosphere and can cause tremendous consequences in the environment.

**Natural Chemical Weathering**

Plants can cause both mechanical and chemical weathering. Mechanical weathering occurs when roots grow and cause the rock to break, as discussed above. Chemical weathering occurs when chemicals are released by the roots of plants, like acid-producing Lichen, that break down rocks.
Oxidation

Oxidation is the reaction of rock minerals with oxygen, thus changing the mineral composition of the rock. When minerals in rock oxidize, they become less resistant to weathering. Iron, a commonly known mineral, becomes red or rust colored when oxidized.

Hydrolysis

Hydrolysis is a chemical reaction caused by water. Water changes the chemical composition and size of minerals in rock, making them less resistant to weathering.

Effects of Climate

The climate affects the rate of weathering. Climate is the pattern of weather that occurs in a particular area over many years. In cold climates, where freezing and thawing are frequent, mechanical weathering rapidly breaks down rock through the process of ice wedging. Chemical weathering is more rapid in warm, wet climates. Thus, chemical weathering occurs quickly in tropical areas such as the Amazon River region of South America. Lack of moisture in deserts and low temperatures in the polar regions slow down chemical weathering. Which type of weathering do you think is more rapid where you live?
The Nature of Soil

Formation of Soil

How often have you been told “Take off those dirty shoes before you come into this house”? Ever since you were a child, you’ve had experience with soil. Soil is found in many places—backyards, empty city lots, farm fields, gardens, and forests.

What is soil and where does it come from? A layer of rock and mineral fragments produced by weathering covers the surface of Earth. As you learned in Section 1, weathering gradually breaks rocks into smaller and smaller fragments. However, these fragments do not become high-quality soil until plants and animals live in them. Plants and animals add organic matter, the remains of once-living organisms, to the rock fragments. Organic matter can include leaves, twigs, roots, and dead worms and insects. Soil is a mixture of weathered rock, decayed organic matter, mineral fragments, water, and air.

Soil can take thousands of years to form and ranges from 60 m thick in some areas to just a few centimeters thick in others. Climate, slope, types of rock, types of vegetation, and length of time that rock has been weathering all affect the formation of soil, as shown in Figure 13. For example, different kinds of soils develop in tropical regions than in polar regions. Soils that develop on steep slopes are different from soils that develop on flat land. Figure 14 illustrates how soil develops from rock.

Figure 13 Five different factors affect soil formation. Explain how time influences the development of soils.
It may take thousands of years to form, but soil is constantly evolving from solid rock, as this series of illustrations shows. Soil is a mixture of weathered rock, mineral fragments, and organic material—the remains of dead plants and animals—along with water and air.

A Natural acids in rainwater weather the surface of exposed bedrock. Water can also freeze in cracks, causing rocks to fracture and break apart. The inset photo shows weathered rock in the Tien Shan Mountains of Central Asia.

B Plants take root in the cracks and among bits of weathered rock—shown in the inset photo above. As they grow, plants, along with other natural forces, continue the process of breaking down rocks, and a thin layer of soil begins to form.

C Like the grub in the inset photo, insects, worms, and other living things take up residence among plant roots. Their wastes, along with dead plant material, add organic matter to the soil.

D As organic matter increases and underlying bedrock continues to break down, the soil layer thickens. Rich topsoil supports trees and other plants with large root systems.
Composition of Soil

As you have seen already, soil is made up of rock and mineral fragments, organic matter, air, and water. The rock and mineral fragments found in soils come from rocks that have been weathered. Most of these fragments are small particles of sediment such as clay, silt, and sand. However, some larger pieces of rock also might be present.

Most organic matter in soil comes from plants. Plant leaves, stems, and roots all contribute organic matter to soil. Animals and microorganisms provide additional organic matter when they die. After plant and animal material gets into soil, fungi and bacteria cause it to decay. The decayed organic matter turns into a dark-colored material called humus (HYEW mus). Humus serves as a source of nutrients for plants. As worms, insects, and rodents burrow throughout soil, they mix the humus with the fragments of rock. Good-quality surface soil has approximately equal amounts of humus and weathered rock material.

Soil has many small spaces between individual soil particles that are filled with water or air. When soil is moist, the spaces hold the water that plants need to grow. During a drought, the spaces are almost entirely filled with air.

The Soil Profile

As soils develop over time, layers (or horizons) form a soil profile. Most soil profiles cover the earth as 2 main layers—topsoil and subsoil.

Soil horizons are the layers in the soil as you move down the soil profile. A soil profile may have soil horizons that are easy or difficult to distinguish.

Most soils exhibit 3 main horizons:

- **A horizon**—humus-rich topsoil where nutrient, organic matter and biological activity are highest (i.e. most plant roots, earthworms, insects and micro-organisms are active). The A horizon is usually darker than other horizons because of the organic materials.
- **B horizon**—clay-rich subsoil. This horizon is often less fertile than the topsoil but holds more moisture. It generally has a lighter color and less biological activity than the A horizon. Texture may be heavier than the A horizon too.
- **C horizon**—underlying weathered rock (from which the A and B horizons form). Some soils also have an **O horizon** mainly consisting of plant litter which has accumulated on the soil surface.

The properties of horizons are used to distinguish between soils and determine land-use potential.
mainly consisting of plant litter which has accumulated on the soil surface.

humus-rich topsoil where nutrient, organic matter and biological activity are highest

clay-rich subsoil. This horizon is often less fertile than the topsoil but holds more moisture

underlying weathered rock (from which the A and B horizons form)

Figure 15 Soil profile showing the different layers or horizons.

Factors Affecting Soil Formation

Soil forms continuously, but slowly, from the gradual breakdown of rocks through weathering. Weathering can be a physical, chemical or biological process:

- **physical weathering**—breakdown of rocks from the result of a mechanical action. Temperature changes, abrasion (when rocks collide with each other) or frost can all cause rocks to break down.
- **chemical weathering**—breakdown of rocks through a change in their chemical makeup. This can happen when the minerals within rocks react with water, air or other chemicals.
- **biological weathering**—the breakdown of rocks by living things. Burrowing animals help water and air get into rock, and plant roots can grow into cracks in the rock, making it split.
The accumulation of material through the action of water, wind and gravity also contributes to soil formation. These processes can be very slow, taking many tens of thousands of years. Five main interacting factors affect the formation of soil:

- **parent material**—minerals forming the basis of soil
- **living organisms**—influencing soil formation
- **climate**—affecting the rate of weathering and organic decomposition
- **topography**—grade of slope affecting drainage, erosion and deposition
- **time**—influencing soil properties.

Interactions between these factors produce an infinite variety of soils across the earth’s surface.

**Parent materials**

Soil minerals form the basis of soil. They are produced from rocks (parent material) through the processes of weathering and natural erosion. Water, wind, temperature change, gravity, chemical interaction, living organisms and pressure differences all help break down parent material.

The types of parent materials and the conditions under which they break down will influence the properties of the soil formed. For example, soils formed from granite are often sandy and infertile whereas basalt under moist conditions breaks down to form fertile, clay soils.

**Organisms - Life in the Soil**

Soil formation is influenced by organisms (such as plants), micro-organisms (such as bacteria or fungi), burrowing insects, animals and humans.

As soil forms, plants begin to grow in it. The plants mature, die and new ones take their place. Their leaves and roots are added to the soil. Animals eat plants and their wastes and eventually their bodies are added to the soil.

This begins to change the soil. Bacteria, fungi, worms and other burrowers break down plant litter and animal wastes and remains, to eventually become organic matter. This may take the form of peat, humus or charcoal.
Climate

Temperature affects the rate of weathering and organic decomposition. With a colder and drier climate, these processes can be slow but, with heat and moisture, they are relatively rapid.

Rainfall dissolves some of the soil materials and holds others in suspension. The water carries or leaches these materials down through the soil. Over time this process can change the soil, making it less fertile.

Different types of soil are found in different climate biomes.

Figure 17 Temperature affects the rate of weathering and organic decomposition. Different types of soil are found in different biomes.
Soil Types
If you travel across the country and look at soils, you will notice that they are not all the same. Some soils are thick and red. Some are brown with hard rock nodules, and some have thick, black A horizons. Many different types of soils exist, as shown in Figure 18.

Soil Types Reflect Climate. Different regions on Earth have different climates. Deserts are dry, prairies are semidry, and temperate forests are mild and moist. These places also have different types of soils. Soils in deserts contain little organic material and also are thinner than soils in wetter climates. Prairie soils have thick, dark A horizons because the grasses that grow there contribute lots of organic matter. Temperate forest soils have thinner A horizons than prairie soils do. Tree roots and leaves cannot deliver as much organic matter to deeper parts of the soil as grasses can deliver. Other regions such as tundra and tropical areas also have distinct soils.
Topography

The shape, length and grade of a slope affects drainage. The aspect of a slope determines the type of vegetation and indicates the amount of rainfall received. These factors change the way soils form.

Soil materials are progressively moved within the natural landscape by the action of water, gravity and wind (for example, heavy rains erode soils from the hills to lower areas, forming deep soils). The soils left on steep hills are usually shallower.

Figure 19 The slope of the land affects soil development. Thin, poorly developed soils form on steep slopes, but valleys often have thick, well-developed soils. Infer why this is so.
Time

Soil properties may vary depending on how long the soil has been weathered. Minerals from rocks are further weathered to form materials such as clays and oxides of iron and aluminum.

Summary

Formation of Soil
- Soil is a mixture of rock and mineral fragments, decayed organic matter, water, and air.

Composition of Soil
- Organic matter in soil is gradually changed to humus.
- Soil moisture is important for plant growth.

Soil Profile
- The layers in a soil profile are called horizons.
- Most soils have an A, B, and C horizon.

Soil Types
- Many different types of soils occur in the United States.
- Climate and other factors determine the type of soil that develops.

Self Check

1. List the five factors that affect soil development.
2. Explain how soil forms.
3. Explain why A horizons often are darker than B horizons or C horizons.
4. Describe how leaching affects soil.
5. Think Critically Why is a soil profile in a tropical rain forest different from one in a desert? A prairie?
Soil Erosion and Conservation

Soil: An Important Non-Renewable Resource

While picnicking at a local park, a flash of lightning and a clap of thunder tell you that a storm is upon you. Watching the pounding rain from the park shelter, you notice that the water flowing off of the ball diamond is muddy, not clear. The flowing water is carrying away some of the sediment that used to be on the field. This process is called soil erosion. Soil erosion is harmful because plants do not grow as well when topsoil has been removed.

Causes and Effects of Soil Erosion

Soil erodes when it is moved from the place where it formed. Erosion occurs as water flows over Earth’s surface or when wind picks up and transports sediment. Generally, erosion is more severe on steep slopes than on gentle slopes. It’s also more severe in areas where there is little vegetation. Under normal conditions, a balance between soil production and soil erosion often is maintained. This means that soil forms at about the same rate as it erodes. However, humans sometimes cause erosion to occur faster than new soil can form. One example is when people remove ground cover. Ground cover is vegetation that covers the soil and protects it from erosion. When vegetation is cleared, as shown in Figure 15, soil erosion often increases.

Trees protect the soil from erosion in forested regions. When forest is removed, soil erodes rapidly.

Figure 21 Removing vegetation can increase soil erosion.
Agricultural Cultivation Soil erosion is a serious problem for agriculture. Topsoil contains many nutrients, holds water well, and has a porous structure that is good for plant growth. If topsoil is eroded, the quality of the soil is reduced. For example, plants need nutrients to grow. Each year, nutrients are both added to the soil and removed from the soil. The difference between the amount of nutrients added and the amount of nutrients removed is called the nutrient balance. If topsoil erodes rapidly, the nutrient balance might be negative. Farmers might have to use more fertilizer to compensate for the nutrient loss. In addition, the remaining soil might not have the same open structure and water-holding ability that topsoil does.

Forest Harvesting When forests are removed, soil is exposed and erosion increases. This creates severe problems in many parts of the world, but tropical regions are especially at risk. Each year, thousands of square kilometers of tropical rain forest are cleared for lumber, farming, and grazing. Soils in tropical rain forests appear rich in nutrients but are almost infertile below the first few centimeters. The soil is useful to farmers for only a few years before the topsoil is gone. Farmers then clear new land, repeating the process and increasing the damage to the soil.

Overgrazing In most places, land can be grazed with little damage to soil. However, overgrazing can increase soil erosion. In some arid regions of the world, sheep and cattle raised for food are grazed on grasses until almost no ground cover remains to protect the soil. When natural vegetation is removed from land that receives little rain, plants are slow to grow back. Without protection, soil is carried away by wind, and the moisture in the soil evaporates.

Excess Sediment If soil erosion is severe, sediment can damage the environment. Severe erosion sometimes occurs where land is exposed. Examples might include strip-mined areas or large construction sites. Eroded soil is moved to a new location where it is deposited. If the sediment is deposited in a stream, as shown in Figure 22, the stream channel might fill.

Figure 22 Erosion from exposed land can cause streams to fill with excessive amounts of sediment. Explain how this could damage streams.
Preventing Soil Erosion

Each year more than 1.5 billion metric tons of soil are eroded in the United States. Soil is a natural resource that must be managed and protected. People can do several things to conserve soil.

Manage Crops

All over the world, farmers work to slow soil erosion. They plant shelter belts of trees to break the force of the wind and plant crops to cover the ground after the main harvest. In dry areas, instead of plowing under crops, many farmers graze animals on the vegetation. Proper grazing management can maintain vegetation and reduce soil erosion. In recent years, many farmers have begun to practice no-till farming. Normally, farmers till or plow their fields one or more times each year. Using no-till farming, seen in Figure 23, farmers leave plant stalks in the field over the winter months. At the next planting, they seed crops without destroying these stalks and without plowing the soil. Farm machinery makes a narrow slot in the soil, and the seed is planted in this slot. No-till farming provides cover for the soil year-round, which reduces water runoff and soil erosion. One study showed that no-till farming can leave as much as 80% of the soil covered by plant residue. The leftover stalks also keep weeds from growing in the fields.

Figure 23 No-till farming decreases soil erosion because fields are not plowed.
Reduce Erosion on Slopes

On gentle slopes, planting along the natural contours of the land, called \textit{contour farming}, reduces soil erosion. This practice, shown in \textbf{Figure 24}, slows the flow of water down the slope and helps prevent the formation of gullies. Where slopes are steep, terracing often is used. \textbf{Terracing} (TER uh sing) is a method in which steep-sided, level topped areas are built onto the sides of steep hills and mountains so that crops can be grown. These terraces reduce runoff by creating flat areas and shorter sections of slope. In the Philippines, Japan, China, Hawaii and Peru, terraces have been used for centuries.

Reduce Erosion of Exposed Soil

A variety of methods are used to control erosion where soil is exposed. During the construction process water is sometimes sprayed onto bare soil to prevent erosion by wind. When construction is complete, topsoil is added in areas where it was removed and trees are planted. At strip mines, water flow can be controlled so that most of the eroded soil is kept from leaving the mine. After mining is complete, the land is reclaimed. This means that steep slopes are flattened and vegetation is planted.
Summary
Soil—An Important Resource
• Soil erosion is a serious problem because topsoil is removed from the land.
Causes and Effects of Soil Erosion
• Soil erosion occurs rapidly on steep slopes and areas that are not covered by vegetation.
• The quality of farmland is reduced when soil erosion occurs.
Preventing Soil Erosion
• Farmers reduce erosion by planting shelter belts, using no-till farming, and planting cover crops after harvesting.
• Contour farming and terracing are used to control erosion on slopes.

What have you learned about weathering, erosion and soil?

1. Weathering helps to shape Earth’s surface.
2. Mechanical weathering breaks apart rock without changing its chemical composition. Plant roots, animals, and ice wedging are agents of mechanical weathering.
3. Chemical weathering changes the chemical composition of rocks. Natural acids and oxygen in the air can cause chemical weathering.
4. Soil is a mixture of rock and mineral fragments, organic matter, air, and water.
5. A soil profile contains different layers that are called horizons.
6. Climate, parent rock, slope of the land, type of vegetation, and the time that rock has been weathering are factors that affect the development of soil.
7. Soil is eroded when it is moved to a new location by wind or water.
8. Human activities can increase the rate of soil erosion.
9. Windbreaks, no-till farming, contour farming, and terracing reduce soil erosion on farm fields.

Self Check
1. Explain why soil is important.
2. Explain how soil erosion damages soil.
3. Describe no-till farming.
4. Explain how overgrazing increases soil erosion.
5. Think Critically How does contour farming help water soak into the ground?
Lesson Review

1. Describe mechanical and chemical weathering and provide an example of each.

2. Draw and label a sketch of a soil profile.

3. What techniques do farmers use to help conserve topsoil?

4. Name the five main interacting factors that affect the formation of soil.

5. _______________ refers to the natural processes that break rock into smaller and smaller pieces.
   A. subduction
   B. Weathering
   C. Oxidation
   D. Erosion

6. Growing the same crop in the same field year after year will eventually __________.
   A. deplete the nutrients needed to support that crop
   B. make the soil increasingly rich in nutrients
   C. cause widespread erosion