Chapter 23

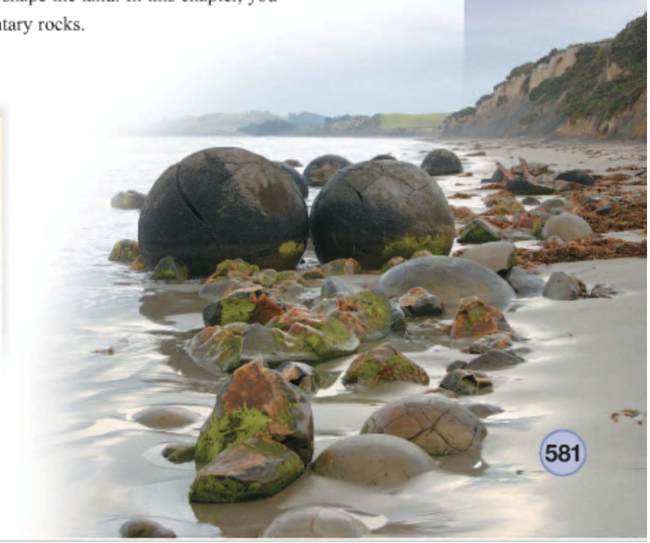
How Water Shapes the Land

If you were to go to the south end of the South Island of New Zealand and walk out on Koekohe Beach, you would see the Moerkai Boulders. Scientists think it took about five million years for the boulders to form and even longer for them to look the way they do now. How did these groupings of large, spherical boulders get on the beach? Where did they come from? The local legend states that the boulders are the remains of baskets and food washed ashore when an ancient sailing canoe overturned. What might be the scientific explanation for the presence of these boulders?

The focus of this chapter is how water—such as flowing water or the ice of glaciers— and other agents such as wind and even the force of gravity shape the land. In this chapter, you will also learn how pieces of rock become new sedimentary rocks.

Key Questions

- ✔ *What is the difference between weathering and erosion?*
- ✔ *How do flowing water and the ice of glaciers shape the land?*
- ✔ *How are sedimentary rocks formed?*



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23.1 Weathering and Erosion

You know from experience that rocks are hard objects. Sitting on a stone bench is not as comfortable as sitting on a sofa. And it takes a lot of work to break a rock into pieces. Over time though, rock does break down. This chapter describes how that happens and how rock is moved from place to place. *Weathering* is a term that describes how rock is broken down to form sediment. *Erosion* describes the transportation of sediment by water, wind, ice, and gravity. In time, even the hardest rock will weather to form small pieces and particles of sediment.

VOCABULARY

weathering - the process of breaking down rocks and minerals.

erosion - the process of moving rock and sediment by wind, water, ice, and gravity.

Comparing weathering and erosion

Weathering You have seen the effects of weathering if you have noticed cracks in a sidewalk or a large rock. You are seeing weathering in action if you have seen lichens or moss growing on a rock. **Weathering** is the process of breaking down rocks and minerals in place, with no movement. Weathering is caused by the formation of ice or salt crystals, changes in pressure, chemical reactions, and the actions of plants or animals.

Erosion Weathering eventually breaks rock into bits and pieces called *sediment* (Figure 23.1). When you sit on a sandy beach, you are sitting on sediment that might once have been a rocky mountaintop. How does sediment get from a mountain peak to a beach? The answer is erosion. **Erosion** is the process of moving pieces of rock and sediment by wind, water, ice, and gravity.

Weathering breaks down rock in place.
Erosion moves rock and sediment.

Energy and the rock cycle In Chapter 18, you learned about the rock cycle. Earth's internal energy drives the rock cycle. Heat energy inside Earth results in the movement of lithospheric plates on Earth's surface so that mountains form and rocks are recycled. Earth's internal energy and the Sun are the two main sources of energy that cause weathering and erosion, two processes in the rock cycle. The Sun drives the water cycle and weather patterns. Water and weather affect the landscape all the time.

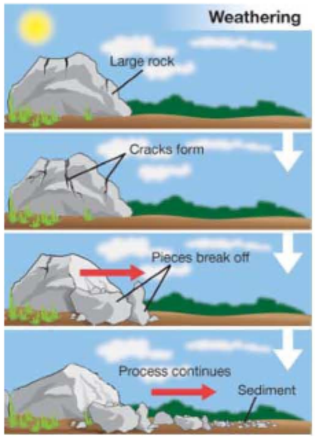

Figure 23.1: *Weathering causes rock to break down into sediment.*

Forms of weathering

Two forms of weathering The two major forms of weathering are mechanical weathering and chemical weathering. Rocks can be weathered by either form or by both. From the images in Figure 23.2, can you figure out the difference between chemical and mechanical weathering?

Mechanical weathering **Mechanical weathering** (also called physical weathering) happens when forces break or chip rocks and minerals into smaller pieces without changing their composition. The formation of ice or salt crystals provides forces for breaking rock. Changes in pressure and the activities of living organisms also provide forces that are sufficient for breaking down rocks.

Chemical weathering **Chemical weathering** is the process of breaking down rocks and minerals by chemical reactions between water and the rock or mineral particles. Other agents of chemical weathering include oxygen and acids (from plants or acid rain). Minerals and rocks are chemically changed by this type of weathering. Some types of rocks are weathered more easily than others. For example, marble chemically weathers faster than granite. Chemical weathering has worn away the surfaces of many old marble statues (Figure 23.2).

Soil is the result of weathering

The process of weathering affects sediment as well as rocks and minerals. In time, sediment combines with organic matter, making a rich mixture called soil (see the photo at the left). Soil also includes air, water, and living organisms such as bacteria, fungi, and insects. The quality of soil depends on the "parent material," or type of rocks that are broken down to form it. Some parent rocks might produce rock grains with an abundance of minerals necessary for plant growth. Other parent rocks might lack a key mineral and produce soil that supports less or no plant growth. Where might soil be located relative to the parent material? Because of erosion by wind, water, and the force of gravity pulling sediment downhill, soil is often located at a distance from the parent material.

VOCABULARY

mechanical weathering - the process of breaking down rocks and minerals into smaller pieces by physical force without changing composition; also called physical weathering.

chemical weathering - the process of breaking down rocks and minerals by chemical reactions.

Figure 23.2: *Mechanical and chemical weathering.*

Processes of mechanical weathering

Frost wedging

Frost wedging happens when water enters a crack in a rock and then freezes. Once the water freezes, it expands and the crack gets wider. If the process continues through many freeze-thaw cycles, the rock will eventually split into separate pieces. Frost wedging tends to happen in areas with available water and temperatures that fluctuate around the freezing point. Rocks that have many pores or cracks are susceptible to frost wedging. The photo in Figure 23.3 shows an example of frost wedging near the crest of Mount Hoffman in Yosemite National Park, California. You can see in the photo that many hand-sized rocks have been broken away by frost wedging.

Salt crystal weathering

In dry, hot environments and along coastlines, the growth of salt crystals can cause mechanical weathering. Dry, hot environments are places where salty solutions on rocks will evaporate quickly. Coastal environments are continuously subjected to salt water that leaves behind salt crystals once it evaporates. Salt crystals cause weathering because their formation and expansion within pores or cracks in rocks causes the rocks to weather. Salt crystals expand when they are heated. As you can see in the images below, weathering by salt crystals leaves interesting patterns. The image on the left shows salt weathering of stone bricks. The image on the right is an example of a *tafoni* formation. Tafoni formations are believed to be caused by salt weathering and other processes.

Salt weathering of stone bricks

Tafoni formation near San Francisco

VOCABULARY

frost wedging - mechanical weathering that results from freezing water.

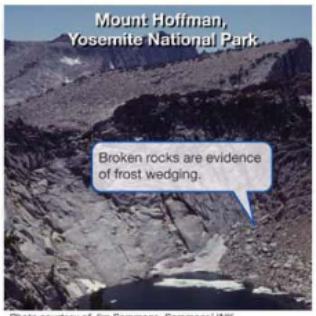

Photo courtesy of Jim Sammons, Sammons' INK.

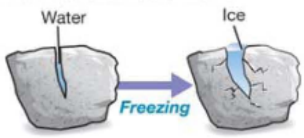

Figure 23.3: *An example of frost wedging.*

Changes in temperature and pressure

Changes in temperature and pressure also cause mechanical weathering. For example, in desert environments, the air temperature changes from hot during the day to cold at night. As you learned in Chapters 9 and 10, matter expands when its temperature increases. When rock expands as it is heated, the outer layers crack and split away. This process is called *exfoliation*. Exfoliation also happens when erosion removes outer layers of rock, causing inner layers to experience a decrease in pressure. Half Dome in Yosemite National Park is an example of how rock appears after pressure changes.

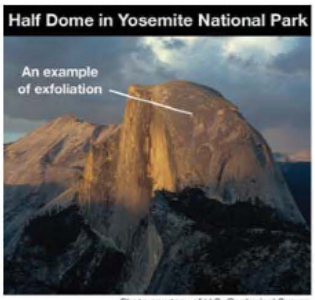

Photo courtesy of U.S. Geological Survey

Unloading and exfoliation domes

Half Dome is a mountain composed of intrusive igneous rock, meaning it was formed underground. After erosion exposed the mountain and removed its outer layers (like peeling an onion), the inner layers experienced decreased pressure and expanded. Expansion caused cracking of the newly exposed rock. In time, pieces of the rock broke off. This process is called *unloading*. The combination of erosion, unloading, and exfoliation has made Half Dome an example of an *exfoliation dome*. Geologists think that another “half” of Half Dome never existed. The flat face of Half Dome is the result of erosion of the original rock by Ice Age glaciers.

Biological weathering

Mechanical and chemical weathering by plants or animals is called *biological weathering*. An example of mechanical weathering by plants happens when roots grow into cracks in a rock. In this process, called *root wedging*, roots exert force on the rock as they grow and might cause the rock to split (Figure 23.4). Animals contribute to weathering when they dig into soil or burrow underground (Figure 23.5). The resulting holes and burrows become passageways for water to move deeper underground and speed up the weathering of underground rocks. Human activities—such as blasting rock to build roads—also cause mechanical weathering.

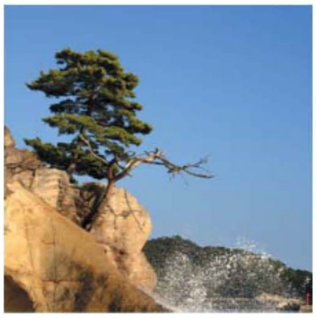

Figure 23.4: *Over time, the roots of trees will split the rocks on this cliff by root wedging.*

Figure 23.5: *Burrowing animals create pockets for water to move underground and weather rocks.*

Agents of chemical weathering

Water Water is often called a universal solvent because it dissolves many substances, including minerals in rock. Chemical changes can happen when minerals are exposed to water. Minerals might dissolve or a new mineral might be made. For example, the mineral feldspar reacts with water to form clay minerals, which are softer, meaning they have a lower number on the Mohs hardness scale. These clay minerals are more susceptible to erosion.

Acid rain As precipitation, water also dissolves carbon dioxide gas from the atmosphere. You read in Chapter 21 that dissolved carbon dioxide in water makes it a weak acid. For this reason, rainwater is naturally slightly acidic. Water that has a pH less than 5.6 is considered to be acid rain. Acid rain forms when pollutants or volcanic gases in the atmosphere acidify rainwater. Acid rain can weather rocks, including statues. If the statues are made of marble, they will weather more quickly than those made of granite (see the statue in Figure 23.2). Marble is made of calcite (calcium carbonate), which dissolves in acidic water. By comparison, granite statues do not weather as fast when exposed to acid rain because they contain minerals, like quartz, that are more resistant to chemical weathering.

Oxygen in the atmosphere Oxygen found in the atmosphere or dissolved in water also participates in weathering. Oxygen combines with metals in minerals and changes them. This process is called *oxidation*. For example, oxygen combines with iron in the minerals biotite and hornblende to make iron oxide, or rust. Rust commonly appears on iron-containing objects such as nails or bicycles that have been exposed to water.

Biological weathering Lichens and plants such as moss can cause chemical weathering. Chemicals released by the plants eventually cause the rock on which they are growing to break down (Figure 23.6).

The two forms of weathering act together Both chemical and mechanical weathering can affect a rock at the same time. Look at Figure 23.7. Here you see large cracks that might have been created by frost wedging. Cracks and loose sediment in the cracks have provided a place for plants to take root. Now, the rock will further break down as the growing plants cause both chemical and mechanical weathering.

Figure 23.6: *Moss growing on rocks causes chemical weathering.*

Figure 23.7: *Both mechanical and chemical weathering often occur at the same time.*

Factors that affect the rate of weathering

Water and climate The presence of water and an area's climate determine the type of weathering that takes place and how fast it happens. For example, frost wedging is common in cold and dry climates with frequent, often daily, freeze-thaw cycles. Chemical weathering is slowest in dry, cold climates. Rocks and minerals tend to chemically weather much faster in areas that have humid, warm climates. In general, chemical weathering is more likely to happen in humid or wet conditions.

Plants and animals Weathering is also faster when biological weathering is possible. Plants growing on or near rocks can speed up weathering. Animals digging or burrowing increases how much exposure a rock has to weathering.

Minerals The type of minerals found in a rock also affects how fast the rock weathers. As you learned on the previous page, calcite in marble weathers faster than the minerals in granite. This is because calcite dissolves in acidic solutions (for example, acid rain). However, granite has other minerals, such as feldspar, that are susceptible to weathering. Feldspar chemically weathers to form clay.

Surface area Weathering commonly involves contact with water. Therefore, the greater the surface area of a rock or mineral compared to its volume, the faster it will weather. For example, a thin, jagged rock will weather more quickly than a thick, rounded rock of the same volume (Figure 23.8). The thin, jagged rock has a greater surface area to volume ratio. You can increase the surface area to volume ratio of any solid by breaking it down into pieces.

The importance of weathering You might consider that weathering is a negative process because it breaks down rocks and structures that have been constructed by humans. However, weathering is important to life on Earth. Why? Weathering releases minerals in rocks so that they can become part of the soil. These minerals are then available as nutrients for plants to absorb. Animals and people are able to absorb these nutrients by consuming plants. Important chemical elements such as calcium (for building strong bones and teeth) and iron (for your blood) are originally from rocks.

JOURNAL

Nutrition from Rocks

Macronutrients and trace minerals are important components of a healthy diet.

Research the definition of *macronutrients* and *trace minerals.* Then, pick a macronutrient and a trace mineral to research. Answer the following questions.

1. What food sources supply this macronutrient?

2. How is this macronutrient important for the healthy functioning of your body?

3. Why are the "minerals" you eat called "minerals"?

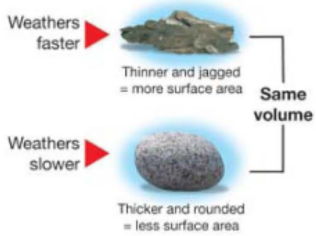

Figure 23.8: *A thin, jagged rock has a greater surface area to volume ratio than a thick, rounded rock.*

Erosion

What is erosion? What happens after rock is weathered? The weathered fragments move! Through erosion, rock, rock pieces, sediment, and soil are transported by water, wind, ice, and other agents. Other agents include the force of gravity, which causes rock and sediment to move downhill, and erosion caused by animals (such as the overgrazing of livestock, which disturbs more soil and thus exposes it to increased erosion).

Water and wind erosion Water is a powerful force involved in erosion. You will learn more about water erosion in Section 2 of this chapter. Wind is also a powerful force that moves particles of sediment from one place to another. Small particles might be carried aloft by the wind. Larger particles and rocks are too heavy to be moved by the wind. Larger particles are rolled along on the ground, and the big rocks don't move. The result might be a rocky desert pavement left behind after the removal of soil over time (Figure 23.9). Eroded sediment is eventually deposited when the wind dies down. Beach dunes are one example of large amounts of wind-deposited sand. *Loess* is another wind-blown deposit of fine sediment. Loess is an important resource because the deposit is rich with nutrients and makes good soil for growing plants.

The mystery of the Moeraki Boulders At the beginning of this chapter, you read about the Moeraki Boulders in New Zealand. The mystery behind these boulders is related to both weathering and erosion. Before the boulders formed, some type of material, probably the remains of something that was once alive, were included in layers of fine sediment. As these sediment layers were changed into mudstone, a type of sedimentary rock, mineral crystals replaced this once-living material. The mass of crystals is called a *concretion*. Millions of years later, the mudstone began to weather away, forming silt and leaving the more durable concretions—the Moeraki Boulders—behind. The boulders have moved only a little since they were exposed but the material surrounding them eroded. In other words, the main movement was the inland movement of the mudstone cliff face near the beach as it was washed away (Figure 23.10).

Figure 23.9: *Results of wind erosion.*

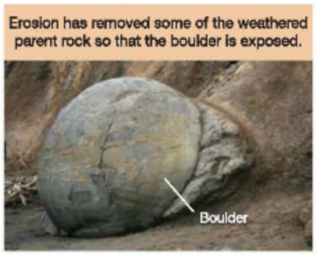

Figure 23.10: *A Moeraki boulder.*

Moving sediment by gravity

Mass wasting **Mass wasting** is a form of erosion that involves the downhill movement of large amounts of rock and sediment due to the force of gravity. Examples of mass wasting include landslides, rockfalls, mudflows, and slumps.

Landslides A *landslide* happens when a large mass of soil or rock slides down a steep slope. Wet conditions or a volcanic eruption can trigger a landslide. For example, the largest landslide ever recorded took place in 1980 when Mount St. Helens erupted.

Landslide

Photo courtesy Department of Defense

Rockfalls In the mountains, it is common to see boulders alongside the rock outcrops that line the road. A *rock outcrop* is the part of a rock formation that is above ground and visible. A *rockfall* happens when a boulder is split off of a rock outcrop due to weathering or another event. Rockfalls speed up the weathering process by quickly breaking up large pieces of a rock formation.

Rockfall

Photo courtesy Colorado Department of Transportation (CDOT)

Mudflow A *mudflow* occurs when a large amount of rock and sediment mixed with water flows down a mountain. Water adds weight to and lubricates the rock and sediment, reducing friction. Mudflows can be dramatic and fast events. They flow down a mountain very quickly, engulfing everything in their paths. The eruption of Mount St. Helens involved mudflows. Mudflows on and around a volcano are called *lahars*. Mud on a volcano is made from volcanic ash.

Slumping *Slumping* occurs when loose soil becomes wet and slides, or "slumps" (Figure 23.11). When soil is dry, friction between the grains of soil keeps it firm enough that you can build a house on it. However, if the soil is wet, the spaces between the grains are full of water. The water makes the grains slippery and friction is a lot lower. Slumping can happen after a period of very heavy rainfall.

Slump

Photo by Robert L. Schuster, USGS

VOCABULARY

mass wasting - the downhill movement of large amounts of rock and sediment due to the force of gravity.

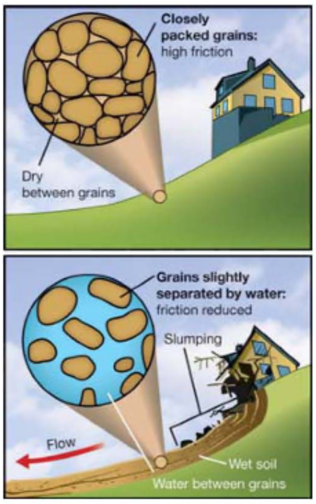

Figure 23.11: *Houses are at risk of being damaged or destroyed by slumping when they are built on steep, loose soil or below hills that are made of loose soil.*

Section 23.1 Review

1. Compare and contrast weathering and erosion.
2. What energy sources drive weathering and erosion?
3. Explain the difference between mechanical and chemical weathering.
4. For the following examples, state whether mechanical or chemical weathering is occurring.
   a. A bicycle left in the rain becomes rusty.
   b. Water in a crack in a rock freezes causing the rock to split.
   c. A rock is covered with moss and lichens.
   d. An inscription on a 200-year-old marble slab is no longer legible.
   e. Salt crystals grow in the cracks of coastal rocks.
5. How is frost wedging similar to root wedging?
6. How are animals involved in the processes of weathering and erosion?
7. List the two events that lead to exfoliation.
8. Explain the role of water in chemical weathering.
9. What happens when carbon dioxide and air pollutants mix with rainwater? Is the resultant rainwater an agent of weathering or erosion?
10. Over time, how might the grass growing up through a crack in a sidewalk affect the sidewalk? Use the terms *mechanical weathering* and *chemical weathering* in your answer.

11. List three factors that affect how fast a rock weathers.
12. Explain how the process of weathering benefits living organisms.
13. Which area might experience more soil erosion: a grassy field or an area that has been cleared of vegetation to construct a building? Why?
14. Explain the role of gravity in erosion.
15. Describe two examples of mass wasting. Is mass wasting a form of weathering or erosion? Explain your answer.

SCIENCE FACT

The Rate of Erosion

The following factors increase the rate of erosion for rocks and soil.

Climatic factors:
Precipitation, temperature, and stormy weather.

Type of rock and its location:
Porous rock will erode faster; rock that is on a hill will erode faster.

Amount of weathering that a rock has experienced:
Weathered rock erodes faster than unweathered rock.

The lack of vegetation:
The root systems of trees, grass, and other plants protect soil from being eroded.

The presence of plants or animals:
Plant growth and animal movement can cause weathering that leaves rock and soil more vulnerable to erosion.

Human activity:
Any activity that removes trees and other plants from the land or that disturbs soil or rock makes an area susceptible to erosion.

Soil erosion is a very serious and little understood problem. Find out more about this global issue and write a short paragraph about it.