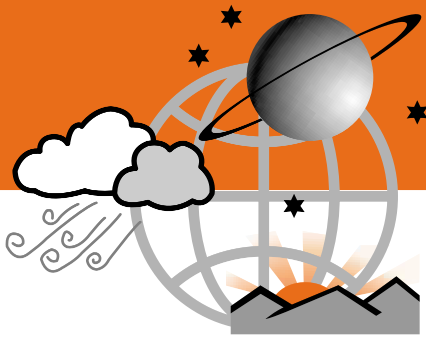


Chapter 10

Weathering and Soils

WHAT IS WEATHERING?

As you look around at the natural environment, you probably notice many changes. You notice the apparent motion of the sun through the sky from morning to evening. Stars move through the night sky, and the phases of the moon follow a cycle. The weather, especially temperature, sky conditions, and precipitation, changes from day to day. These are changes that happen quickly enough to affect our lives from day to day.

The solid Earth is also changing. In Chapter 8, you learned that energy flow by convection within the planet causes mountains to rise. Meanwhile, the processes of weathering (the breakdown of rock) and erosion (the carrying away of the pieces) cut down and reshape the land surface. Unless there is a sudden geological event, such as an earthquake or a flood, these changes are too slow to affect us on a day-to-day basis. It is important to realize that even through some changes in the natural environment are not apparent, over the hundreds, thousands, millions, and even billions of years these slow changes are important to us. Weathering is a good example of a slow process that, through thousands of years, can

Figure 10-1 Formations such Escalante Arch in Utah are temporary features in the long-term history of Earth's surface.

radically change the shape of the land. Scientists realize that features like the rock arch in Figure 10-1 are just temporary in the long-term reshaping of the land.

Most of the rocks you see were formed underground. If rocks stayed in the same location and under the same conditions as where they formed, they would probably be stable. But when rocks are exposed to conditions at Earth's surface they change. This change is called **weathering**. Weathering is influenced by exposure to wind, water, oxygen, plants, and animals. All of these agents contribute to breaking down **bedrock**, the solid, or continuous, rock that extends into Earth's interior. (See Figure 10-2.) The weathering of rock creates a loose substance known as **sediment**.

Physical Weathering

Weathering processes can be classified as physical changes or chemical changes. **Physical weathering**, also known as **mechanical weathering**, breaks rocks into smaller particles. However, the chemical (mineral) composition of the particles does not differ from the composition of the original rock.

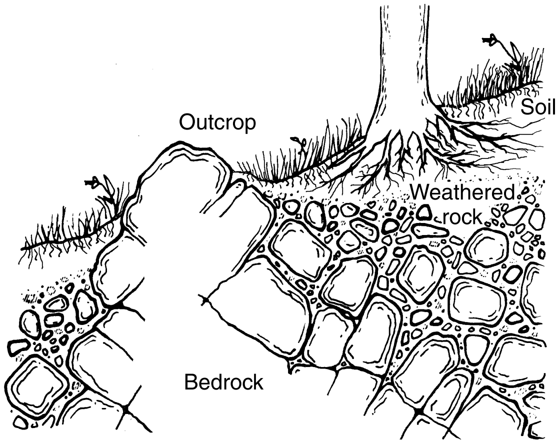


Figure 10-2 Bedrock is the solid rock that extends into the ground. An outcrop is bedrock that is exposed at the surface. At other places, soil or water covers the bedrock.

FROST WEDGING A good example of mechanical weathering is **frost wedging**. This kind of weathering is active in moist places where the temperature alternates between day temperatures above the freezing point of water and colder night temperatures that are below freezing. Water is sometimes trapped in cracks in rock at the surface. Water is one of the few substances that expands when it forms a solid. If this were not true, ice would sink in water. Rivers and lakes would freeze from the bottom up, killing fish and other organisms that can survive only in liquid water. With repeated cycles of freezing and thawing, frost wedging widens the cracks, gradually forcing the rock apart. The force created when water freezes can also open new cracks for water to enter. In this way, solid rock is continuously broken into smaller fragments.

BIOLOGICAL ACTIVITY Rocks are also broken apart by **biological activity**. If a tree or another plant grows its roots into a crack in solid rock, the roots apply a constant pressure that can help break the rock apart. (See Figure 10-3 on page 242.) Lichens and mosses sometimes grow on rock surfaces. These tiny plants also help break the rock apart. Burrowing animals such as earthworms, ants, woodchucks, and rabbits create passages through soil and allow both water and air to come into contact with unweathered or partially weathered rock.

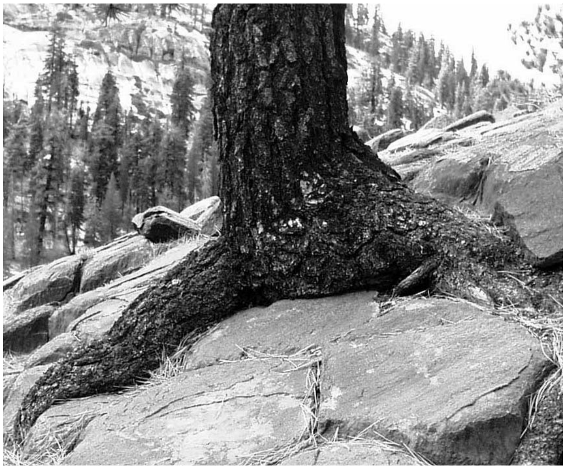


Figure 10-3 Plants help to break rocks apart when their roots grow into cracks in the rock.

EXFOLIATION Granite forms by slow cooling and crystallization well below Earth's surface. When granite solidifies, the rock is under great pressure caused by the weight of rocks above it. If thousands of years of uplift, weathering, and erosion cause the granite to be exposed at Earth's surface, there is a great reduction in pressure. As a result, the granite near the surface expands and cracks into slabs that break away from the solid bedrock. There is no change in composition involved in this process, so it is a physical change. Figure 10-4 shows expanding granite slabs near Yosemite Valley in California.

ABRASION The grinding away of rock by friction with other rocks is **abrasion**. Abrasion is another kind of physical, or

Figure10-4. The slabs of rock on this granite surface formed when a release of pressure caused the rock to crack parallel to the exposed surface.

mechanical, weathering. Wind, water, or glaciers are transporting agents that carry rocks and sediment. The transporting agent causes pieces of rock to collide or rub against one another and against the bedrock rock over which they are carried. Consider a large rock that has broken off bedrock near the head of stream. It is likely that at some point the rock will fall into the stream and begin its slow journey downstream. Repeated collisions with other rock fragments gradually wear down the rock as it is transported downstream. So what began as a large piece of solid rock near the head of a stream is transformed into small bits of sediment as it travels downstream. The farther rocks are transported, the smaller they become.

Resistance to Weathering

Not all rocks are worn down at the same rate. The harder a rock is, the more resistant it is to physical, or mechanical, weathering. Resistance to abrasion depends on the mineral composition of a rock and how the rock is held together. For example, quartz is a relatively hard mineral with a Mohs' scale hardness of 7. A rock of solid quartz is likely to be worn down very slowly. Although sandstone is often composed of quartz particles, sandstone will weather quickly when the quartz grains are not securely cemented. Limestone is made primarily of calcite, which has a Mohs' hardness of only 3. But a solid layer of limestone can be more resistant to abrasion and other forms of physical weathering than poorly cemented sandstone.

The Grand Canyon in Arizona is nearly 2 km deep. The walls of the canyon expose more than a dozen different rock formations. The most resistant layers form the steepest rock faces because they wear away slowly and have the most strength. The weaker layers tend to form terraces because soft rocks do not have the strength to hold up as cliffs. Weak rocks can also be found as indentations or notches protected above and below by stronger rocks. Figure 10-5 on page 244 shows the cliff and terrace nature of the Grand Canyon.

Figure 10-5 As shown in this photograph of the Grand Canyon, the most resistant rock layers form steep cliffs. The weaker rocks weather to form terraces and gentle slopes.

ACTIVITY 10-1 ROCK ABRASION

Materials: rock chips, mass scale, wide-mouth plastic jar with lid, sieve or strainer, plastic bucket

You can simulate the conditions in a fast-moving stream by placing rock chips and water in a wide-mouth plastic jar and shaking the jar. Before beginning the activity, your teacher will have soaked the rock chips in water for an hour or more. At the beginning of the activity, find the mass of approximately 100 grams of rock chips to the nearest 0.1 gram. Place a few centimeters of water in the plastic jar, add the rock chips, and screw the top on tightly. (Be sure the jar does not leak.) Shake the jar vigorously for 4 minutes. Using a strainer to catch the rock chips, pour the water into a bucket Find the mass of rock remaining after shaking and record it.

Repeat the procedure with the same rock fragments, shaking them for two additional 4-minute intervals. Record the mass of rock remaining after each 4 minutes of shaking. Graph the initial mass and the mass after each 4 minutes of shaking. If different groups use different kinds of rock, compare the data to decide which kind or kinds of rock are abraded more quickly.

Chemical Weathering

Sometimes the weathering process does more than simply break the rocks apart. If you find a steel nail that has been exposed to the weather for a long time, it will probably be rusted. Rusting is a **chemical change**, which results in the formation of a new substance. Iron, the major component of steel, can combine chemically with oxygen in the atmosphere to form rust (iron oxide). The presence of moisture accelerates the rusting process. This is a form of chemical weathering because a new substance (rust) is formed. **Chemical weathering** is a natural process that occurs under conditions at Earth's surface, forming new compounds. Although steel is not found in nature, many minerals do contain iron. Iron is often one of the first components to weather. When iron combines with oxygen in the atmosphere it forms iron oxide, which gives rock a rusty red to brown color. The chemical equation for this change is (Fe is the chemical symbol for iron)

$$4Fe + 3O_2 \rightarrow 2Fe_2O_3$$

$$\text{iron} + \text{oxygen} \rightarrow \text{iron oxide}$$

Calcite, the principal mineral in limestone and marble, is chemically weathered by water that is acidic. The chemical formula for limestone is $CaCO_3$ (calcium carbonate). Rainwater absorbs carbon dioxide as it falls through the atmosphere, making rain a mild acid. This is not strong enough to hurt you or your clothing, but it can slowly break down limestone. When rainwater infiltrates the ground, it picks up more carbon dioxide from decaying plant remains. The acid (represented by H^+) can then react with limestone. The chemical equation for this change is written as

$$CaCO_3 + 2H^+ \rightarrow Ca^{2+} + H_2O + CO_2$$

$$\begin{matrix}\text{calcium} \\ \text{carbonate}\end{matrix} + \text{acid} \rightarrow \begin{matrix}\text{calcium} \\ \text{ions}\end{matrix} + \text{water} + \begin{matrix}\text{carbon} \\ \text{dioxide}\end{matrix}$$

This process forms limestone caverns, such as Howe Caverns and Secret Caverns near Cobleskill, New York. Although

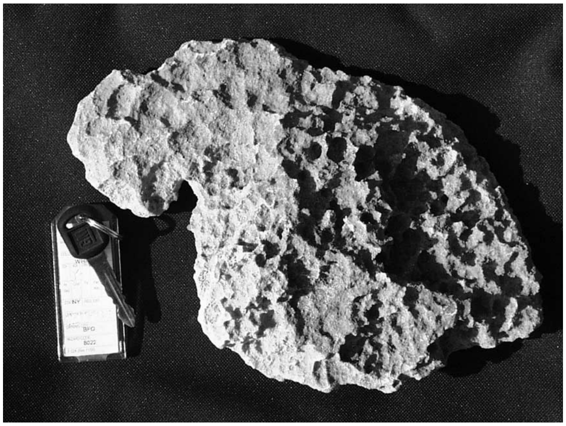


Figure 10-6 This sample of limestone has been shaped by chemical weathering as natural acids in rainfall have partly dissolved the calcite.

the longest limestone caverns in New York State have been explored to about 10 km, Mammoth Caves in Kentucky are known to have more than 500 km of connected underground passages. Figure 10-6 shows a sample of limestone that has been weathered by natural acids in rainwater.

Limestone and marble make excellent building stones, although the calcite in them has a hardness of only 3 on Mohs' scale. These rocks are soft enough to be cut into blocks but strong enough to support the weight of a large building. Limestone and marble are also relatively easy to shape into sculptures and ornamentation. Many of our historic buildings are built with limestone and marble. Unfortunately, as cities have developed into centers of industry and commerce, air pollution has weathered the surface of some of these buildings.

Sulfur dioxide primarily from the burning of fossil fuels is a source of sulfuric acid when it combines with moisture in the atmosphere. When combined with moisture in the atmosphere, nitrogen oxides from motor vehicles and electrical power plants form nitric acid. When acid precipitation falls on limestone and marble it changes the mineral calcite into a chalky powder. Many historic buildings and outdoor statues in Europe and North America have been damaged by acid weathering. This is a major reason there are laws to limit acid pollution. Although these measures cannot restore damaged structures, they have slowed the further chemical weathering of buildings and monuments made of limestone and marble.

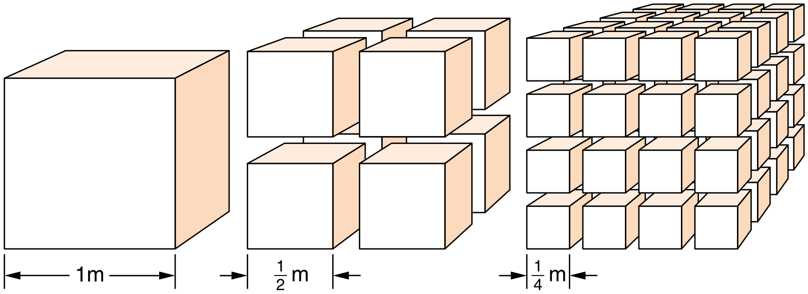


Figure 10-7 As solid rock is broken into smaller pieces, its total surface area increases. Additional surface area can increase the rate of weathering.

SURFACE AREA Figure 10-7 shows that breaking a rock into smaller fragments increases the surface area of the material. Weathering is active on the surfaces, breaking up a rock exposes more surface area, which accelerates the rate of weathering.

ACTIVITY 10-2 CALCULATING SURFACE AREA

Figure 10-7 shows a single cube of rock 1 meter on each side (A) that is divided into progressively smaller pieces. Calculate the total surface area of the samples in parts A, B, and C of the diagram. Show your work. Start with an algebraic formula, substitute numbers and units, and show the mathematical steps to each solution.

TEACHER DEMONSTRATION REACTION RATE AND SURFACE AREA

(**Caution:** Acids can cause skin burns and damage to clothing. Always handle acids with care.)

Materials: 2 small beakers (50–100 mL), natural chalk, a mortar and pestle, about 25 mL of 1 molar hydrochloric acid.

Break off two equal sized lengths (about 1 cm) of natural chalk. Place the first piece of chalk in a beaker of acid and watch the reaction. Use the mortar and pestle to crush the second piece of chalk into a fine powder. Add the powder to a second beaker containing acid. Why do the reactions in the two beakers differ?

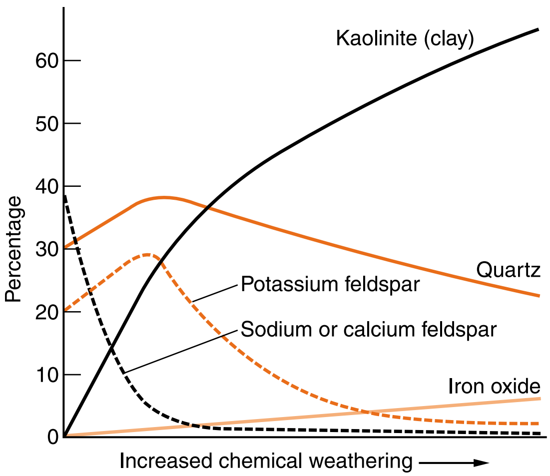


Figure 10-8 Fresh granite is composed primarily of feldspar and quartz. Through a long process of chemical weathering, the primary components change to clay, quartz, and iron oxide."

Feldspar is the most common mineral in rocks at or near Earth's surface. But feldspar is not stable when it is exposed to the atmosphere over very long periods of time. Feldspar weathers to a softer material composed primarily of clay and silica.

Figure 10-8 shows the changing mineral composition of granite as chemical weathering takes place. The unweathered rock is composed primarily of quartz and feldspar. After a long period of weathering, the sediments are mostly clay, quartz, and iron oxide. Of the original minerals, the only one to remain abundant is quartz. This shows that quartz is stable over a wide range of environmental conditions.

ACTIVITY 10-3 CHEMICAL WEATHERING AND TEMPERATURE

Materials: small beakers (100–250 mL), hot and cold running water, thermometers, three to four small pieces of antacid tablets.

In this activity, you will devise your own laboratory procedure. The objective is to find out how temperature affects the rate of a chemical reaction. Once you have planned and written down your procedure, check it with your teacher. When your procedure is approved, perform the experiment and create a data table. Finally, record your conclusion about the effect of temperature on this chemical reaction.

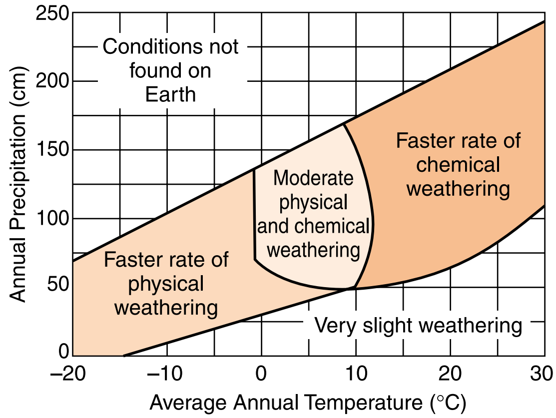


Figure 10-9 Cold climates favor physical weathering, especially frost action. Chemical weathering dominates under conditions of warm temperatures and abundant rainfall.

Factors That Affect Weathering

The amount and kind of weathering that takes place depends on three factors. You have read that the harder a rock is, the more it resists physical weathering. The more chemically stable its minerals are, the better a rock resists chemical weathering. The final factor is climate. Figure 10-9 shows that cold climates tend to favor physical weathering. Daily cycles of temperatures above and below freezing promote frost action in cold climates. Warm and moist climates accelerate chemical changes. For this reason chemical weathering is especially active in tropical locations.

HOW DOES SOIL FORM?

To this point in the chapter, weathering has been considered a destructive process that loosens rock and wears down the land. But weathering is responsible for one of our most important natural resources—soil. **Soil** is a mixture of weathered rock and the remains of living organisms in which plants can grow.

Figure 10-10 on page 250 shows the development of soil on a solid rock surface. In the first column in the diagram, the bedrock is unbroken, but it is exposed to the atmosphere and

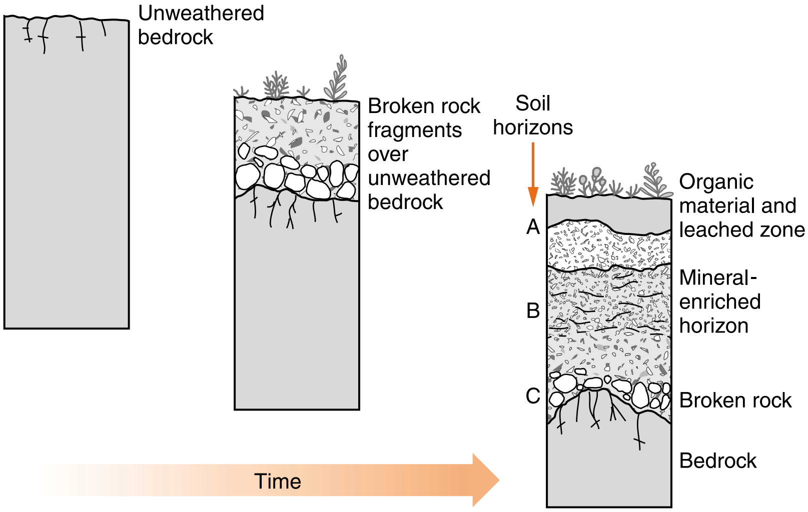


Figure 10-10 Weathering, infiltration of water, burrowing by animals, plant growth, and decay of organic remains contribute to the formation of soil. A mature soil usually develops layering called soil horizons.

weather. The weathering process begins as rainwater reacts with the rock surface and water infiltrates cracks in the rock. Water that seeps into crevices and fissures may change to ice and push the rock apart. Minerals soften and some minerals expand as they react with rainwater and groundwater. The second column shows fragments of broken rock covering solid bedrock. The third column shows a complete soil in which organic remains, mostly dead plant material, have been mixed into the topsoil. **Infiltration** (water seeping into the ground) has carried some water deeper into the soil. The mature soil in the third column shows layering called **soil horizons** that are typical of well-developed soils. The topsoil is usually enriched with organic remains but may lack some soluble minerals that water carried deeper into the soil. As a result, the soil below is enriched in soluble minerals. At the bottom of the soil profile, a layer of broken rock overlies the solid bedrock from which the soil may have formed.

The soil formed at any location depends on the composition of local bedrock, the climate, and the time for development. Warm and moist climates favor chemical weathering and usually produce thick soils, although the movement of groundwater through the soil may wash away important nutrients. Polar locations more often have thin, rocky soils with little chemical weathering. Animals take part in soil forma-

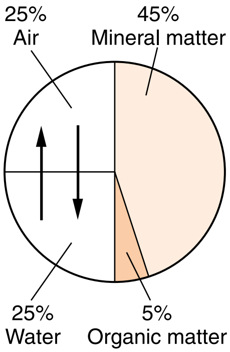


Figure 10-11 The best soils for the growth of most plants contain a mixture of weathered minerals and organic remains. The proportions of air and water depend upon where the soil is located and recent weather conditions.

tion as they burrow by mixing the components of soil (minerals in various states of weathering and organic remains), by loosening soil, and by allowing air and water to circulate.

Active volcanoes can be dangerous, but the soils that result from the weathering of volcanic rocks are usually very fertile. At least two cities were destroyed by the eruption of Mount Vesuvius in southern Italy in 79 CE. In spite of the danger, people soon moved back to the slopes of Vesuvius. The volcano is still active, and another major eruption is possible at any time. In spite of this, farmers are drawn back to the slopes of the mountain by the rich soil.

Figure 10-11 shows the composition of a well-balanced soil. The mineral content provides important nutrients and support for plants. Organic material retains water in the soil and holds the soil together. Water is an essential component for plant growth, but air is also important. Many plants cannot thrive if their roots are submerged in water all the time.

Soil that is formed in place and remains there is called a **residual soil**. Residual soils develop through the processes of weathering over hundreds or even thousands of years. **Transported soil** is formed in one location and moved to another location. In most areas, including New York State, transported soils are more common than residual soils. Continental glaciers that repeatedly formed in Canada and moved southward pushed, carried, and dragged most of our sediment and soil from the place where it formed to New York State. The absence of a layer of broken bedrock that grades into solid rock in most New York locations is evidence of this transportation of soil.

TERMS TO KNOW

abrasion	**frost wedging**	**sediment**
bedrock	**infiltration**	**soil**
biological activity	**mechanical weathering**	**soil horizon**
chemical change	**physical weathering**	**transported soil**
chemical weathering	**residual soil**	**weathering**

CHAPTER REVIEW QUESTIONS

1. How does weathering affect rocks?

(1) Weathering causes the mineral grains to increase in size.
(2) Weathering makes rock harder.
(3) Weathering occurs when sediment changes to sedimentary rock.
(4) Weathering weakens rock so it can be carried away by erosion.

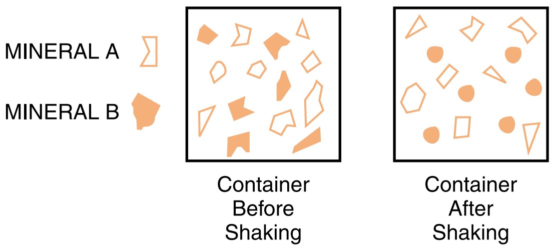
2. A tree growing on bedrock extends its root into a crack in the rock and splits the rock. The action of the root splitting the bedrock is an example of

(1) chemical weathering.
(2) deposition.
(3) erosion.
(4) physical weathering.

3. Which statement best describes physical weathering that occurs when ice forms within cracks in rock?

(1) Physical weathering occurs only in bedrock composed of granite.
(2) Enlargement of the cracks occurs because water expands as it freezes.
(3) The cracks become wider only because of chemical reactions between water and rock.
(4) This type of weathering is most common in regions with warm, humid climates.

4. Two different kinds of minerals, A and B, were placed in the same container and shaken for 15 minutes. The diagrams below represent the size and shape of the various pieces of mineral before and after shaking. What caused the resulting differences in shapes and sizes of the minerals?



(1) Mineral B was shaken harder.
(2) Mineral B had a glossy luster.
(3) Mineral A was more resistant to abrasion.
(4) Mineral A consisted of smaller pieces before shaking began.

5. Which of the following is probably bedrock?

(1) a large boulder transported by a glacier
(2) the solid rock walls of a deep canyon
(3) minerals in a granite block that is part of a new building
(4) a statue of a Greek hero displayed in a museum

6. Which kind of rock is most likely to form new compounds when it is exposed to air polluted with acids?

(1) gneiss
(2) limestone
(3) granite
(4) schist

7. Which geologic feature is caused primarily by chemical weathering?

(1) large caverns in limestone bedrock
(2) a pattern of parallel cracks in a granite mountain
(3) blocks of basalt at the base of a steep slope
(4) the smooth, polished surface of a rock in a dry, sandy area

8. As rock is broken apart by physical weathering processes,

(1) its total surface area decreases.
(2) its total surface area increases.
(3) new minerals form in the rock material.
(4) the mass of the rock increases.

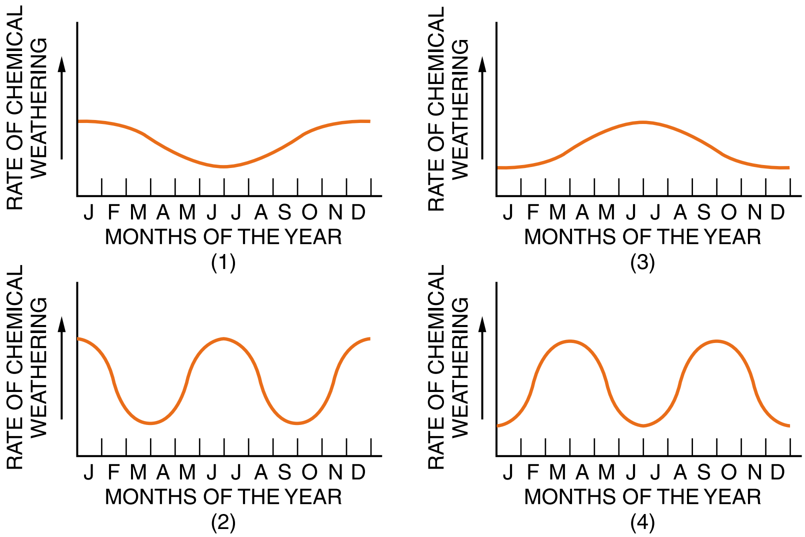
9. Which factor has the greatest influence on the weathering rate of bedrock at Earth's surface?

(1) local air pressure
(2) position of the sun in the sky
(3) local weather and climate
(4) age of the bedrock

10. Marble is a metamorphic rock composed primarily of the mineral calcite. One hundred grams of marble is added to each of two identical beakers of hydrochloric acid. One marble sample is added as coarse marble chips. The second sample is added as a finely ground powder of marble. Why does the fine powder react more quickly with the acid?

(1) Grinding changes the chemical composition of marble.
(2) Fine particles of marble are less dense than coarser particles.
(3) The finely ground powder has a greater total surface area.
(4) The coarse marble chips have a greater total surface area.

11. Assuming that rainfall and other precipitation was constant, which graph below best shows how the amount of chemical weathering changes through the calendar year in New York State?



12. Which of the following changes does *not* directly contribute to the formation of soil?
(1) melting of rock to make molten magma
(2) plant roots growing into cracks in the ground
(3) acidic rainfall reacting with the mineral calcite
(4) rocks split apart by water freezing in cracks

13. A residual soil forms by
(1) cooling of magma.
(2) erosion of weathered rock.
(3) cementing of mineral grains.
(4) physical and chemical weathering.

14. The lowest horizon of a residual soil is composed primarily of
(1) organic remains.
(2) solid bedrock
(3) broken bedrock.
(4) products of intense chemical weathering.

15. Two very old tombstones of the same age sit next to each other in a cemetery. Both of them face south. One was cut from granite and the other was cut from marble. The carved writing on the granite stone is sharp and clear. But similar writing carved in the marble is now hard to read. Why is the writing in granite so much easier to read?

(1) The marble was exposed to greater changes in temperature.
(2) Marble is made of minerals that are less resistant to weathering.
(3) Granite formed from molten magma before the marble was metamorphosed.
(4) Granite is relatively soft because it contains large crystals of quartz.

Open-Ended Questions

Base your answers to questions 16 to 19 on the reading passage below and Map I, which shows the location of major producers of nitrogen oxides and sulfur dioxide and Map II, which shows the average pH of precipitation in the continental United States.

Acid Rain

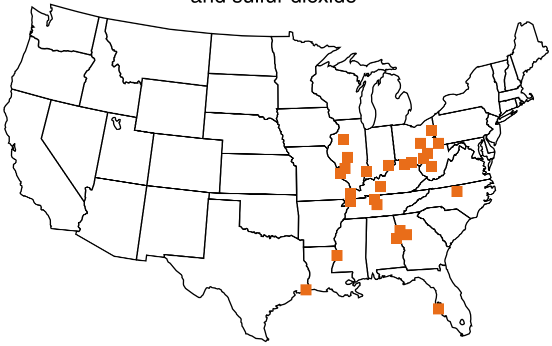
Acid deposition consists of acidic substances that fall to Earth. The most destructive type of acid deposition is rain containing nitric acid and sulfuric acid. Acid rain forms when nitrogen oxides and sulfur dioxide gases combine with water and oxygen in the atmosphere.

Human-generated sulfur dioxide results primarily from coal-burning electric utility plants and industrial plants. Human-generated nitrogen oxide results primarily from burning fossil fuels in motor vehicles and electric utility plants.

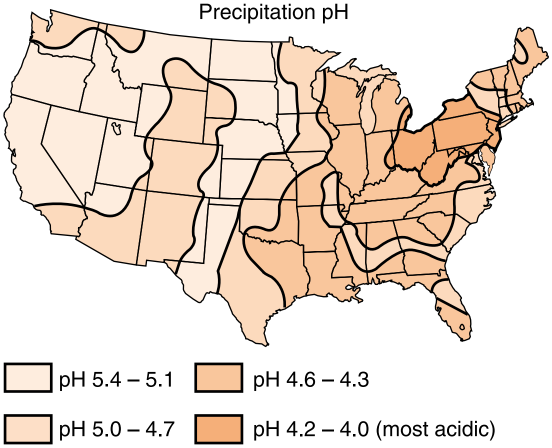
Natural events, such as volcanic eruptions, forest fires, hot springs, and geysers, also produce nitrogen oxide and sulfur dioxide.

Acid rain affects trees, human-made structures, and surface water. Acid damages tree leaves and decreases the tree's ability to carry on photosynthesis. Acid also damages tree bark and exposes trees to insects and disease. Many statues and buildings are composed of rocks containing the mineral calcite, which reacts with acid and chemically weathers more rapidly than other common minerals. Acid deposition lowers the pH of surface water. Much of the surface water in the Adirondack region has pH values too acidic for plants and animals to survive.

Map I
Some major producers of nitrogen oxides and sulfur dioxide



Map II
Precipitation pH



16. State one reason why the northeastern part of the United States has more acid deposition than other parts of the country.

17. Name one sedimentary or one metamorphic rock that is most chemically weathered by acid rain.

18. Describe one law that could be passed by the government to prevent some of the problems of acid deposition.

19. Explain why completely eliminating human-generated nitrogen oxides and sulfur dioxide will not completely eliminate acid deposition.

20. What is the major cause of physical weathering of big rocks transported along a large stream that has a steep gradient.